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A Study of the Effect of Recycling on the Bonding Ability and Characteristics of Fines

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A STUDY OF THE EFFECT OF RECYCLING ON THE BONDING ABILITY AND CHARACTERISTICS OF FINES

by

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ABSTRACT

The recycled paper industry has seemingly grown faster than the technology to go along with it. It has become accepted that along with paper recycles comes a certain amount of strength loss, limiting the uses of secondary fiber. If the recycling industry is continued to grow an effective counter to this strength loss needs to be found. In order to counteract this strength loss the mechanism must first be better understood. The three machanisms that will be focused on for this paper will be 1) The loss of fiber length, 2) Hornification, and 3) The decrease in surface bonding activity. The experimental portion of this project is designed to let two of these mechanisms be eliminated, allowing the third to be more closely examined.

Never-dried softwood fiber was recycled three times; with samples taken at 0, 1, and 3 recycles. Each of these three samples are then screened twice: first using a 150 mesh sieve to extract fines, and secondly using a 32 mesh screen to increase the homogeneity of the long fibers. Handsheets were then made with each of the long fiber / fine combinations and tested for burst, tensile, and Scott Bond.

The results show the extreme importance of fines to paper strength. It was found that by adding never-dried fines to thrice recycled long fibers, the tensile strength could be raised almost 20%. As a matter of fact, even the addition of thrice recycled fines increased all of the strength properties tested. The most dramatic change was seen with Scott Bond, which almost doubled with the addition of fines. This data as a whole shows hornification to be the largest contributor to strength loss because of the fact that even the thrice dried fines bond well.

This experiment could have been more valuable had the recycles been taken to a point where the fines began having a negative effect on bonding. No sources could be found that suggested fines would have a positive effect for even three recycles.

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INTRODUCTION

It is proposed that by the year 2000, close to 50% of all paper made in the United States will be made using recycled stock. One of the main problems with using recycled fiber is the decrease in strength that occurs. This decrease in strength is mainly due to fiber hornification and an increase in fines from refining these stiffened fibers (1). As the paper goes through repeated recycling treatment, this increase in fiber fines eventually becomes detrimental to the strength of the paper. The possible ways to change, or at least adjust, paper strength properties are by blending in virgin fiber, chemical reprocessing, chemical additives, adjusted refining, and fractionation (2). Each of these methods is rather costly, leading to the acceptance of lower grade paper. As the use of recycled fiber increases, ways of using it on grades that require strength must be found. This will not be accomplished until the strength loss mechanism is better understood.

There are three main ways or 'theories' as to why the strength properties decrease that this project will be centered around: 1) The loss of fiber length, 2) 'Hornification' or stiffening of the fibers, and 3) The change in surface properties that occurs.(3)

The theory that strength loss of recycled pulp comes from the decrease in fiber length is the simplest of the three explanations. With each recycling cycle comes beating and often times a refining stage. Either one of these operations separately, and especially a combination of the two, can greatly decrease the long fiber content. It is common knowledge in the paper industry that the longer fibers have more bonding area and therefore make stronger paper.

The theory of hornification is one that is yet to be fully understood. The consensus is that with recycling fibers tend to lose their swelling capacity, and this irreversible loss is increased with the level and duration of drying (4). One backing to this theory is that there is an irreversible closing-up of micropores and cracks that takes place during the drying of the fiber (5). Others tend to base this theory on the irreversible changes in the capillary system of the fiber cell wall. Yet another possible explanation for hornification is that upon drying, the bonding forces which develop are sufficiently large and regular to unite two or more crystalline region as one, thus restricting the swelling in previously dried fibers (6)

When recycled pulp is made into paper a certain amount of fiber fines is helpful to the overall bonding of the sheet. These fines link the longer fiber together by coagulating and attaching themselves in-between the longer fibers. The actual basis of this study will be to analyze the effect of repeatedly recycled and never-dried fibers and fines in combination with repeatedly recycled and never-dried fines. By analyzing the strength properties of the handsheets from each of the combinations much will be learned about the effect of repeated recycling on the fiber and fine structure. It will be determined whether the loss of fiber length, decreased surface bonding, or 'hornification' is the main factor contributing to the loss of strength of repeatedly recycled fibers.

The third hypothesis that will be considered for this thesis is the change of the surface conditions of the fibers. Accessible hemicelluloses on the surface of fibers, as well as their abundance in the cell wall, enhance both fiber-to-fiber bonding and wet flexibility of the fibers (4). Disappearance of these bonding sites, either through redistribution of fatty acids on the fiber surface or inactivation of the hydroxyl groups by any other mechanism during drying, may reverse the performance of the recycled fibers. It has also been suggested that the formation of hydrophobic molecules is responsible for fiber surface inactivation.(4)

There are many acceptable arguments on these happenings, as well as numerous others. It is very possible that the real answer is a combination of all of these suggestions. Hopefully, this thesis project will help to define the recycled fiber; giving some insight towards the real demon of the recycling process. As more knowledge is gained on the reasoning for strength loss of recycled fiber, the problems will be more easily dealt with.

BACKGROUND

The importance of recycling paper in the future is well documented and the market for recycled products is continuing to expand. The recycling industry seems to have grown faster than the technology that goes along with it. Studies have shown that recycled-pulp properties can be changed or adjusted in the following ways; chemical additives, blending with virgin fiber, chemical reprocessing, and refining. These processes can all be used to combat the strength degradation of the fibers; but none are sufficiently effective. It is also well documented that the strength of the fibers and resulting fibers does decrease with recycling. Tensile and bursting strengths have been found to greatly diminish after repeated recycling. The mechanisms that cause this decrease are the source of an ongoing argument. The literature search for this paper found ten different hypothesis on this subject. Some of these hypothesis are similar and some of them are more speculation than theory; but all of them could be argued. The hypothesis that I encountered are: loss of fiber flexibility, irreversible pore closure, crosslinking between cellulose and hemicellulose, lowering of the degree of polymerization of inter-fiber bonds, reorganization of the cell wall, lowering of bond strength, change in surface conditions of the fibers, hemicellulose loss, inactivation of the fiber surface, microcompressions, decrease in fiber-water interactions, and the electric charge of paper surfaces in water. From this list, I chose to focus on the hypothesis of fiber shortening, hysteresis, and change in surfaces of the fibers.

In order to gain more insight into the actual cause of the strength loss due to recycling; an attempt will be made, in this experiment, to eliminate or at least minimize two of the three causes that have been stated in detail above. This is going to be accomplished by screening and the use of fines.

By screening the long fiber fractions of never-dried, once-recycled, and thrice recycled pulps, the effect of fiber shortening is minimized. The shortening of the long fibers will also be limited because of the use of the lack of a refining stage between recycles. Secondly, by using never-dried, once-recycled, and thrice-recycled fines, the effect of hornification will be eliminated. The fines will act like a sort of glue, agglomerating and forming bridges inbetween the long fibers. An illustration of this mechanism can be seen on the next page (Illustration A). This behavior of the fines allows hornification of them to be ignored, and the surface bonding ability to be focused upon. Also, because the fines at each level will be created from the long fibers by beating, the properties are directly related.

EXPERIMENTAL PROCEDURES

This experiment begins with never-dried, 100% softwood, bleached kraft pulp. The only additive used was .25% formaldehyde, as a preservative. The original consistency of the pulp as 5.27%. The first step was to beater the whole pulp batch, which was estimated to weigh 1,007.5 grams O.D. After three separate, 20 minute, Valley Beater runs of approximately 335 grams, the three runs were recombined to ensure consistency. All Valley beater runs were done to Tappi Standard except for the fact that 335 grams were used instead of the called for 360. From this batch, 1/3 was separated out to be screened at a later date; and the remaining 2/3 was made into handsheets to begin the simulation of a recycle. Approximately one hundred 6 gram handsheets were made. This was done using a Noble & Wood handsheet maker, wet pressing the sheets twice, and sending them through a laboratory cylinder dryer set at 250 degrees Fahrenheit three times. These handsheets were then placed into the Valley Beater the next day, and beaten for 20 minutes. Of these remaining 2/3, 1/3 of this as set aside for screening and the last 1/3 was made into handsheets for the third recycle. Fifty handsheets of approximately 6 grams were made following the same specifications as above. The next day these handsheets were beaten inthe Valley Beater for 20 minutes and set aside for screening. At this point in time there are three pulp samples; never-dried, once-recycled, and thrice recycled. The following table gives the freenesses of each sample after beating and the weighted percentage of fines as reported by the Kajaani fiber length analyzer.

	Never-Dried	Once-Recycled	Thrice-Recycled
Freeness (CSF)	700	640	330
Fines (%distribution)	.49	.60	.62

At this point, the fines were screened out. This was done using a 150 mesh, standard calibrated, 8-inch, laboratory screen. The screening of fines was all done at approximately 1.6% consistency, 1.6 grams at a time. Only 1.6 grams could be screened at once to prevent the sieve from becoming clogged with long fiber, especially with the low freeness of the thrice-recycled pulp. Only 90% of each sample was screened, leaving 34 grams of unscreened pulp for comparison handsheets. The fines screening process produced just under 20 gallons of each fines type; the consistencies of these fines are given below.

	Never-Dried Fines	Once-Recycled Fines	Thrice-Recycled Fines
%Consistency	.0141	.0160	.0169

At this point the long fiber from which the fines had been separated were screened in order to minimize the effect of fiber shortening and to double check that all fines had been removed. The long fiber were screened at the same consistency and method as the fines, except for the fact that a 35 mesh screen was used. The fiber loss from this screening is shown below.

	Never-Dried	Once-Recycled	Thrice Recycled
Fiber Loss (%)	12.8	18.4	19.1

This again shows that there was some fiber shortening that took place and that it did worsen with each recycle.

The next step was to make handsheets with all applicable fiber combinations. The following are the combinations used along with the code that they will be referred to as in the data tables:

Never-dried fiber mixture before any screening -- NDM
Once-recycled fiber mixture before any screening -- 1DM
Thrice-recycled fiber mixture before any screening -- 3DM
Never-dried long fibers after both screenings -- NDL
Once-recycled long fibers after both screenings -- 1DL
Thrice-recycled long fibers after both screenings -- 3DL
Never-dried fines + NDL -- NDF + NDL
Never-dried fines + 1DL -- NDF + 1DL
Never-dried fines + 3DL -- NDF + 3DL
Once-recycled fines + NDL -- 1DF + NDL
Once-recycled fines + 1DL -- 1DF + 1DL
Once-recycled fines + 3DL -- 1DF + 3DL
Thrice-recycled fines + NDL -- 3DF + NDL
Thrice-recycled fines + 1DL -- 3DF + 1DL
Thrice-recycled fines + 3DL -- 3DF + 3DL

Ten handsheets were made of each of these combinations. The target weight was set to be 2.6 grams O.D +- 10%. The fines were added at a weight of 10%, or .26 grams, to give the sheet a total weight of 2.6. This was one to assure that all handsheets are of identical weight and can therefore be directly compared.

The best seven handsheets of each run were then selected for testing. This selection was made first by weight, by cutting the accuracy to +- 5%, and secondly by formation. These handsheets were then tested or tensile, burst, and Scott Bond after being conditioned for 24 hours at 72 degrees F and 50% relative humidity. All of these tests were performed according to Tappi Standards on ISO 9001 certified equipment. All Tappi Standard procedures can be found in the appendices of this report.

RESULTS

The results from the tensile, burst, and Scott Bond tests done on all of the handsheet variations can be seen in the next eleven pages of this report. There is also a series of graphs that have been generated to show the comparisons of the different fine / long fiber combinations. These graphs make up the last 21 pages of the Results section of this report so that they may be incorporated into the discussion.

RESULTS OF TENSILE TESTS ON LONG FIBER / FINES

NEVER-DRIED FINES + 3-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	26.86	2.73	5.919
	28.61	2.78	6.495
	27.25	2.59	5.734
	27.19	2.52	5.631
	25.99	2.73	5.513
	23.57	2.7	5.086
	25.07	2.46	5.04
AVERAGE	26.362857	2.644285	5.631142
STD.DEV.	1.5296378	0.112485	0.462953

NEVER-DRIED FINES + 1-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	25.941	2.76	5.799
	28.33	2.56	5.835
	24.01	2.91	5.57
	29.73	2.86	6.896
	29.09	2.8	6.67
	22.23	2.57	4.734
	25.96	2.59	5.464
AVERAGE	26.470142	2.721428	5.852571
STD.DEV.	2.5500907	0.135586	0.680561

NEVER-DRIED FINES + NEVER-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	25.91	2.18	4.578
	24.85	2.55	5.151
	28.28	2.86	6.545
	27.33	2.43	5.394
	22.951	2.12	3.932
	28.11	2.88	6.473
AVERAGE	26.2385	2.503333	5.3455
STD.DEV.	1.9019773	0.296685	0.943157

RESULTS OF TENSILE TESTS ON LONG FIBER / FINES

1-DRIED FINES + 3-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	20.11	2.49	4.027
	20.83	2.02	3.394
	25.21	2.69	5.391
	22.37	2.34	4.269
	24.37	2.62	5.24
	20.58	2.13	3.559
	24.57	2.66	5.334
AVERAGE	22.577142	2.421428	4.459142
STD.DEV.	1.9744273	0.246659	0.793829

1-DRIED FINES + 1-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	23.84	2.89	5.656
	21.45	3.12	5.503
	25.85	2.91	6.111
	23.15	3.06	5.448
	22.87	2.87	5.35
	23.79	2.61	5.026
	26.131	2.85	5.896
AVERAGE	23.868714	2.901428	5.57
STD.DEV.	1.5313210	0.151980	0.331675

1-DRIED FINES + NEVER-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	22.92	2.65	4.908
	22.251	2.54	4.528
	22.98	2.63	4.763
	28.28	2.8	6.424
	30.54	2.69	6.705
	28.67	2.69	6.143
	26.41	2.63	5.429
AVERAGE	26.007285	2.661428	5.557142
STD.DEV.	3.0652063	0.073373	0.805326

RESULTS OF TENSILE TESTS ON LONG FIBER / FINES

3-DRIED FINES + 3-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	17.57	2.55	3.666
	22.84	2.7	5.044
	18.94	2.51	3.867
	21.36	2.42	4.255
	27.69	2.82	6.37
	20.61	2.83	4.58
	22.92	2.51	4.652
AVERAGE	21.704285	2.62	4.633428
STD.DEV.	3.0389418	0.150996	0.832722

3-DRIED FINES + 1-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	24.57	2.82	5.637
	22.31	2.75	4.963
	20.94	1.79	3.012
	25.96	2.12	4.423
	20.131	2.08	3.342
	20.831	2.54	4.32
	21.47	2.49	4.303
AVERAGE	22.316	2.37	4.285714
STD.DEV.	1.9981359	0.353189	0.829626

3-DRIED FINES + NEVER-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	29	2.76	6.518
	31.62	2.62	6.584
	27.361	2.25	4.942
	27.55	2.67	6.037
	22.25	1.95	3.472
	24.21	2.46	4.814
	22.25	2.65	4.722
AVERAGE	26.320142	2.48	5.298428
STD.DEV.	3.2830926	0.266511	1.049854

RESULTS OF TENSILE TESTS ON LONG FIBER / FINES

3-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	17.461	2.04	2.893
	17.32	2.53	3.594
	14.59	2.2	2.663
	18.02	2.68	4.041
	16.17	2.59	3.5
	18.77	2.48	3.809
	15.92	2.59	3.405
AVERAGE	16.893	2.444285	3.415
STD.DEV.	1.3132009	0.217048	0.451104

1-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	22.17	2.28	4.18
	21.03	2.61	4.52
	21.64	2.41	4.62
	17.1	2.39	3.403
	19.66	2.46	3.964
	18.8	2.48	3.732
AVERAGE	20.066666	2.438333	4.069833
STD.DEV.	1.7511107	0.099902	0.425728

NEVER-DRIED LONG FIBER

	STRENGTH	STRETCH	WORK
	24.99	2.99	6.241
	27.5	2.8	6.328
	23.51	2.6	5.109
	21.67	2.84	5.003
	23.011	2.59	4.887
	22.95	1.89	3.5632
AVERAGE	23.9385	2.618333	5.188533
STD.DEV.	1.8689135	0.353997	0.929107

RESULTS OF TENSILE TESTS ON LONG FIBER / FINES

3-DRIED FIBER MIXTURE

	STRENGTH	STRETCH	WORK
	21.89	2.47	4.334
	21.56	2.48	4.311
	24.621	2.58	5.001
	20.081	2.36	3.764
	21.53	2.39	4.16
	22.53	2.35	4.293
	21.11	2.53	4.25
AVERAGE	21.903142	2.451428	4.301857
STD.DEV.	1.3085506	0.081315	0.338504

1-DRIED FIBER MIXTURE

	STRENGTH	STRETCH	WORK
	23.73	2.31	4.481
	24.04	2.33	4.515
	23.87	2.54	4.969
	23.48	2.41	4.486
	25.66	2.62	5.436
	26.16	2.49	5.304
	21.86	1.99	3.557
AVERAGE	24.114285	2.384285	4.678285
STD.DEV.	1.3240183	0.191076	0.586759

NEVER-DRIED FIBER MIXTURE

	STRENGTH	STRETCH	WORK
	25.71	2.44	5.1
	23.76	2.13	4.171
	25.57	2.48	5.165
	24.29	2.78	5.489
	25.49	2.22	4.507
	25.07	2.39	4.882
AVERAGE	24.981666	2.406666	4.885666
STD.DEV.	0.7203799	0.207176	0.436296

RESULTS OF BURST TESTS ON LONG FIBER / FINES

	3DL	1DL	NDL
	36	30	45.5
	38	33.5	39.5
	29	31	37
	31	26	34
	34	32	41.5
	33	33	45.5
	31	33.5	36
	32	32	37.5
	19	27	44.5
	23.5	27.5	33.5
	28.5	29	43
	28.5	28.5	
	30	31.5	
	31	33	
AVERAGE	30.321428571	30.53571428	39.77272727
STD.DEV.	2.444653628	2.452872119	4.276593995

	3DM	1DM	NDM
	35	40.5	43
	37	40.5	40
	33.5	33.5	45
	31	34.5	39.5
	37.5	40	40
	34	35.5	40
	35	33.5	41.5
	38.5	35	37
	36	35	39
	35	42.5	34.5
	30.5	42	41.5
	35.5	39.5	47.5
	40	39	42.5
	36.5	40.5	42
AVERAGE	35.357142857	37.96428571	40.92857142
STD.DEV.	2.5172871695	3.153593674	3.087168969

RESULTS OF BURST TESTS ON LONG FIBER / FINES

	NDF + 3DL	NDF + 1DL	NDF + NDL
	31	34	41.5
	31	31.5	39
	35	31	38
	32	36.5	41.5
	37	37	36
	33	35.5	40
	34	33.5	40
	40	42.5	40
	43	37.5	41
	35	41.5	46
	37	40	44.5
	40	35.5	38.5
	37	36.5	49
		34	36
AVERAGE	35.769230769	36.17857142	40.78571428
STD.DEV.	3.3591700863	3.292888131	3.518899410

	1DF + 3DL	1DF + 1DL	1DF + NDL
	45	42	46.5
	42	44	46.5
	45	40	44
	42	42.5	38.5
	42.5	38.5	50.5
	46	37	51.5
	39.5	45	36
	45.5	42	39.5
	41.5	40	41
	37	46.5	44.5
	39.5	40	44
	37.5	43	41
AVERAGE	41.916666667	41.70833333	43.625
STD.DEV.	2.9498116701	2.625661292	4.491311055

RESULTS OF BURST TESTS ON LONG FIBER / FINES

	3DF + 3DL	3DF + 1DL	3DF + NDL
	34	39.5	43
	35	38.5	35.5
	43	46	55
	38.5	45.5	44
	35.5	42	42.5
	35	41	40
	39	34	40.5
	40	37.5	46.5
	36.5	47.5	42.5
	39	45.5	43.5
	40.5	35.5	50
	42	32.5	48.5
	39.5	37	44.5
	35	37.5	44
AVERAGE	38.035714286	39.96428571	44.28571428
STD.DEV.	4.704272262	4.584384542	4.542318027

RESULTS OF SCOTT BOND TESTS ON LONG FIBER / FINES

	3DL	1DL	NDL
	95	84	80
	82	92	82
	92	80	82
	93	85	78
	99	86	82
	99	95	85
	99	94	84
	99	94	83
	103	85	82
	103	89	84
	94	101	84
	97	99	80
	95	104	78
	99	98	82
AVERAGE	96.357142857	91.85714285	82.36363636
STD.DEV.	7.0004226415	6.957597521	1.919882916

	3DM	1DM	NDM
	165	153	154
	176	172	160
	162	195	153
	177	200	158
	172	207	151
	165	184	161
	170	189	151
	179	208	166
	178	186	154
	181	183	158
	181	187	158
	161	182	158
	162	187	139
	168	190	152
AVERAGE	171.21428571	187.3571428	155.2142857
STD.DEV.	7.1631853592	13.40899028	6.096586532

RESULTS OF SCOTT BOND TESTS ON LONG FIBER / FINES

	3DF + 3DL	3DF + 1DL	3DF + NDL
	138	154	154
	134	156	169
	133	141	161
	140	156	156
	144	136	154
	144	141	141
	154	162	133
	152	156	148
	162	162	156
	151	156	148
	151	162	147
	143	155	139
	148	164	130
	146	168	131
AVERAGE	145.71428571	154.9285714	147.6428571
STD.DEV.	8.6421288195	9.082670199	11.26693736

RESULTS OF SCOTT BOND TESTS ON LONG FIBER / FINES

	NDF + 3DL	NDF + 1DL	NDF + NDL
	150	145	136
	153	151	143
	156	164	138
	144	153	141
	143	156	147
	144	154	143
	144	157	143
	160	169	136
	151	151	147
	152	156	157
	144	162	143
	133	157	135
	148	157	140
	156	154	137
AVERAGE	147.84615385	156.1428571	141.8571428
STD.DEV.	5.914579319	5.730334605	5.642405045

	1DF + 3DL	1DF + 1DL	1DF + NDL
	153	161	138
	148	158	145
	143	143	154
	160	156	157
	148	158	168
	141	153	149
	142	151	149
	150	141	143
	150	143	137
	138	137	138
	139	143	148
	154	135	154
AVERAGE	147.16666667	148.25	148.3333333
STD.DEV.	6.4269398282	8.564704704	8.701851654

FIGURE 1: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET TENSILE STRENGTH

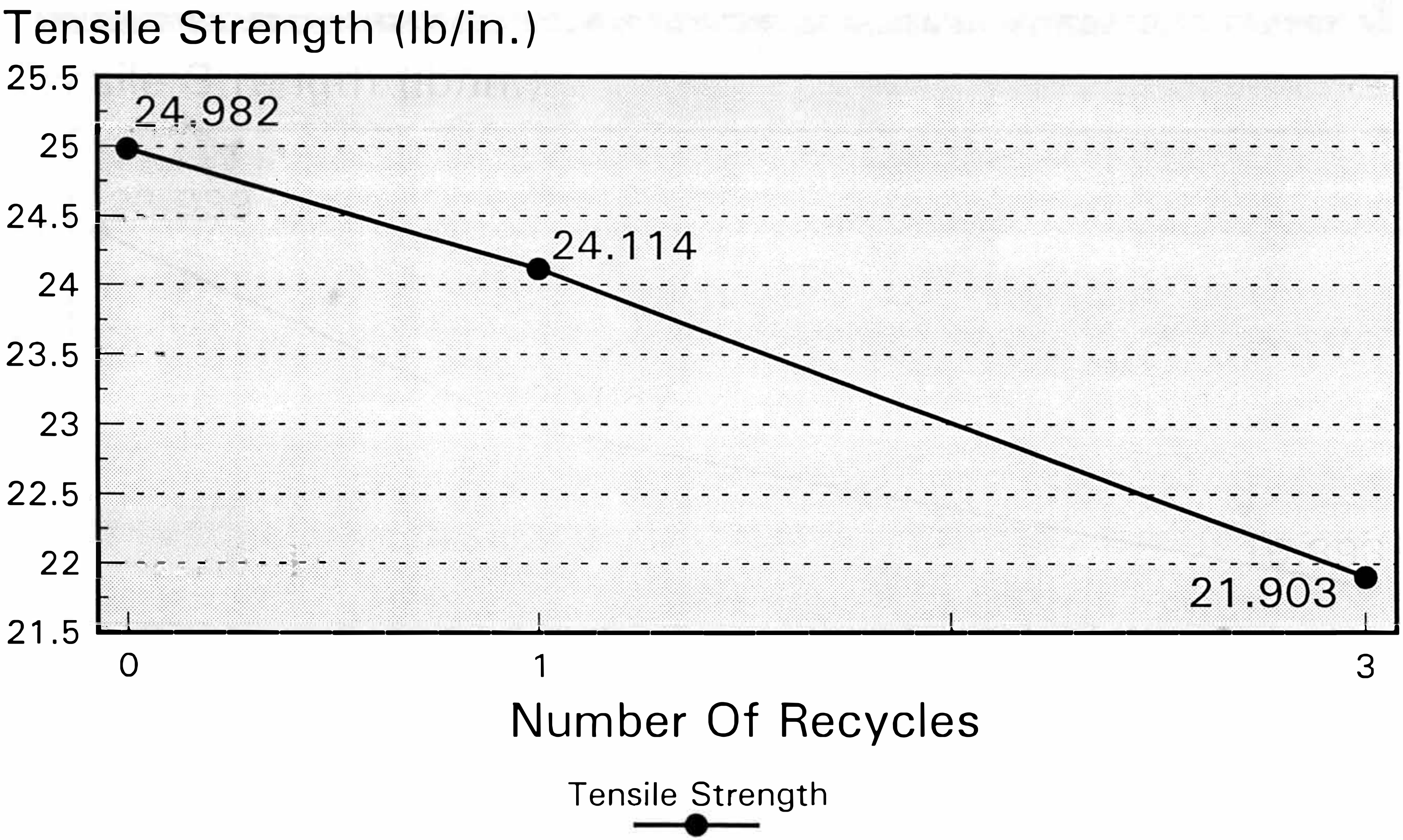


FIGURE 2: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET TENSILE STRENGTH

LONG FIBERS ONLY

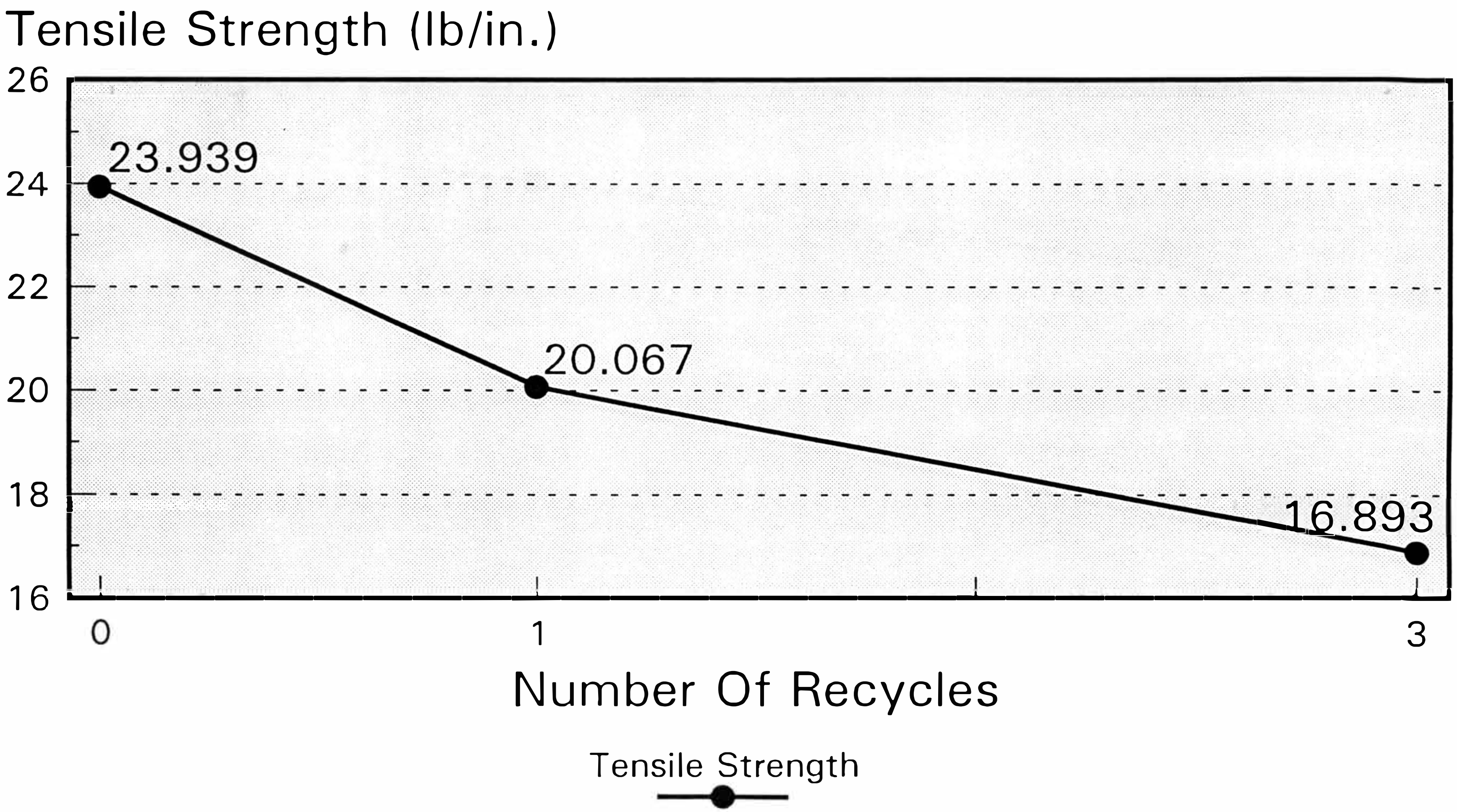
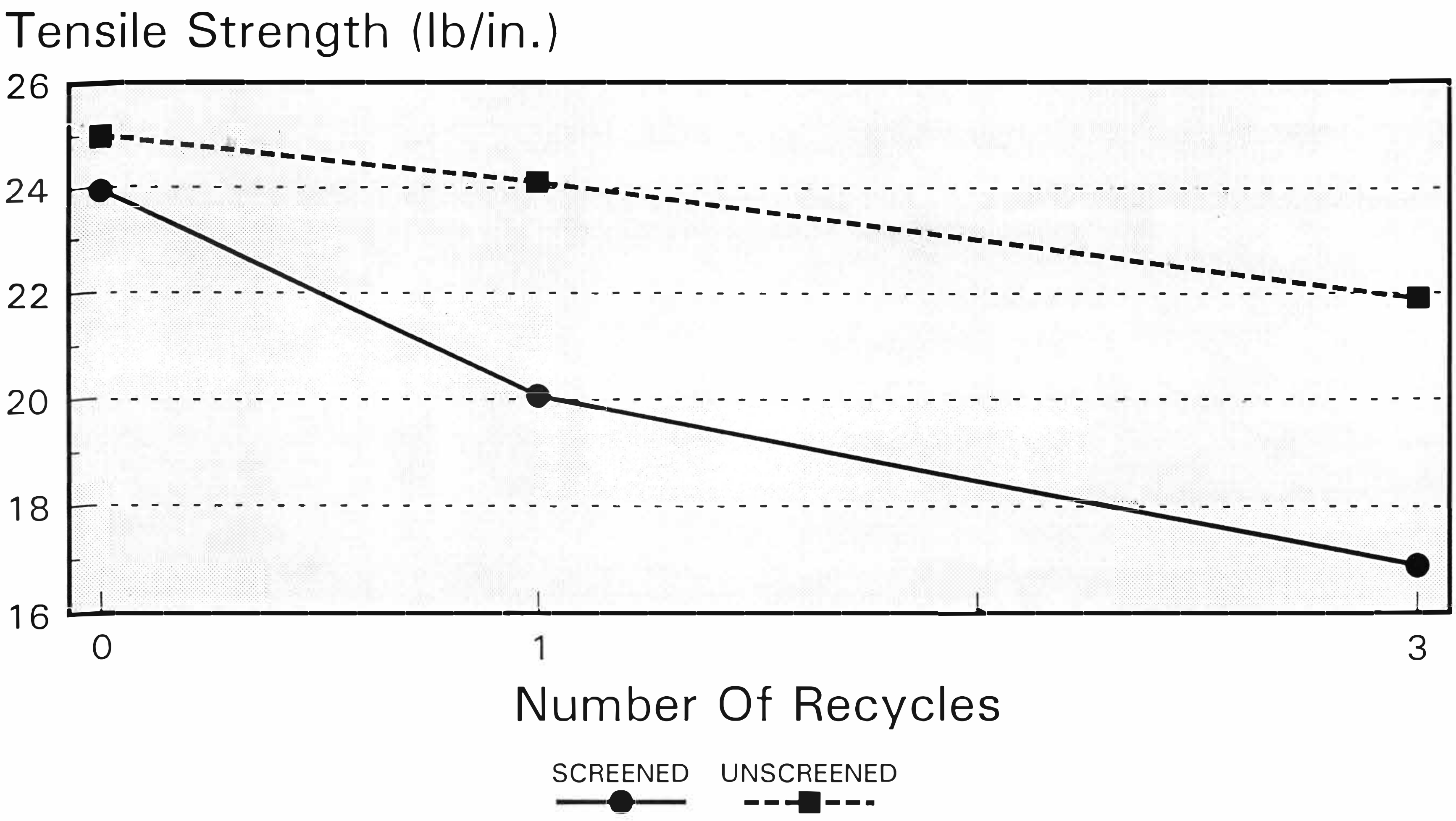


FIGURE 3: THE EFFECT OF NONE, ONE, AND THREE RECYCLES ON HANDSHEET TENSILE STRENGTH

****SCREENED vs. UNSCREENED****



22

FIGURE 4: THE EFFECT OF NEVER-DRIED FINES ON THE TENSILE OF DIFFERENT LONG FIBER COMPONENTS

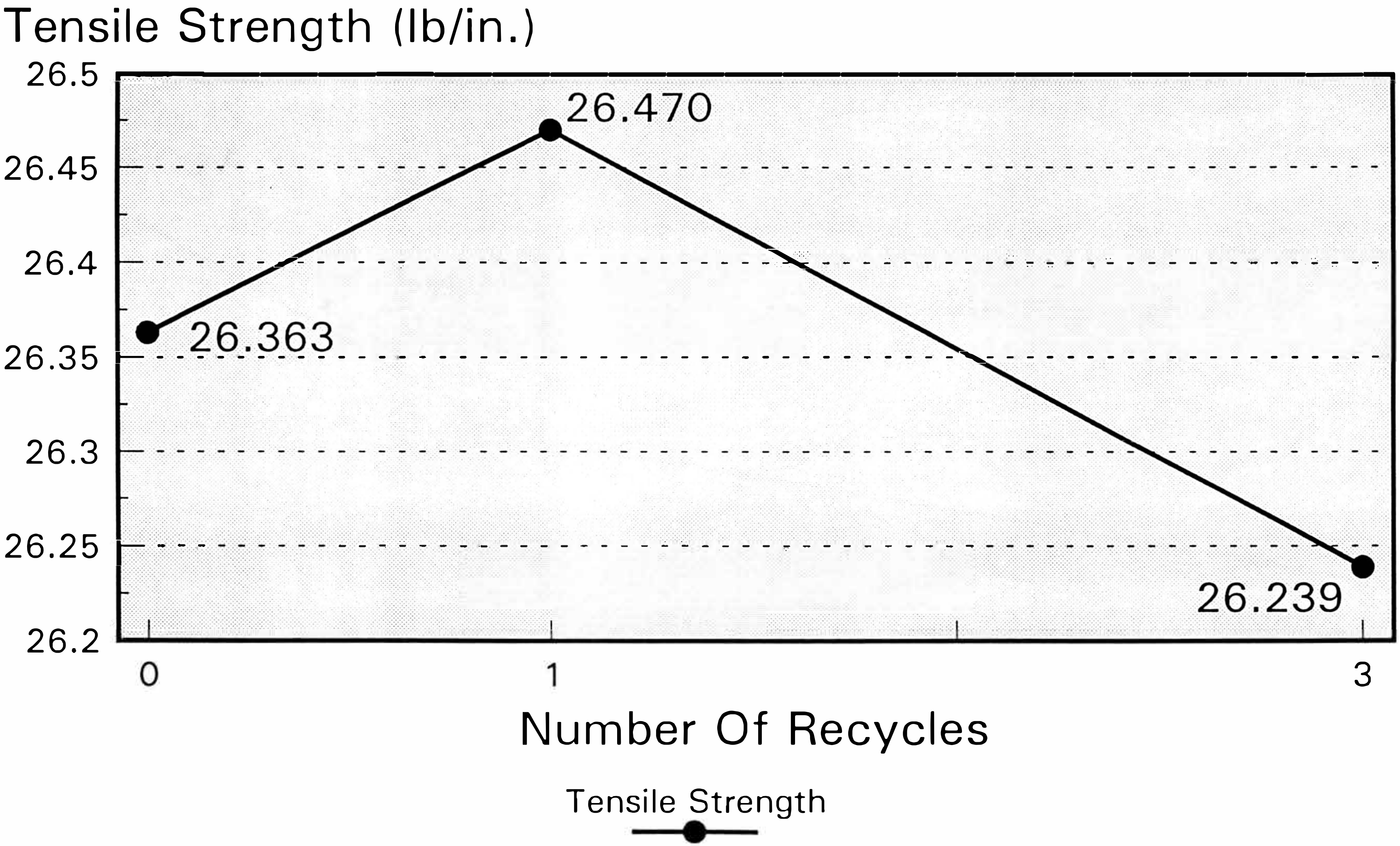


FIGURE 5: THE EFFECT OF ONCE-DRIED FINES ON THE TENSILE OF DIFFERENT LONG FIBER COMPONENTS

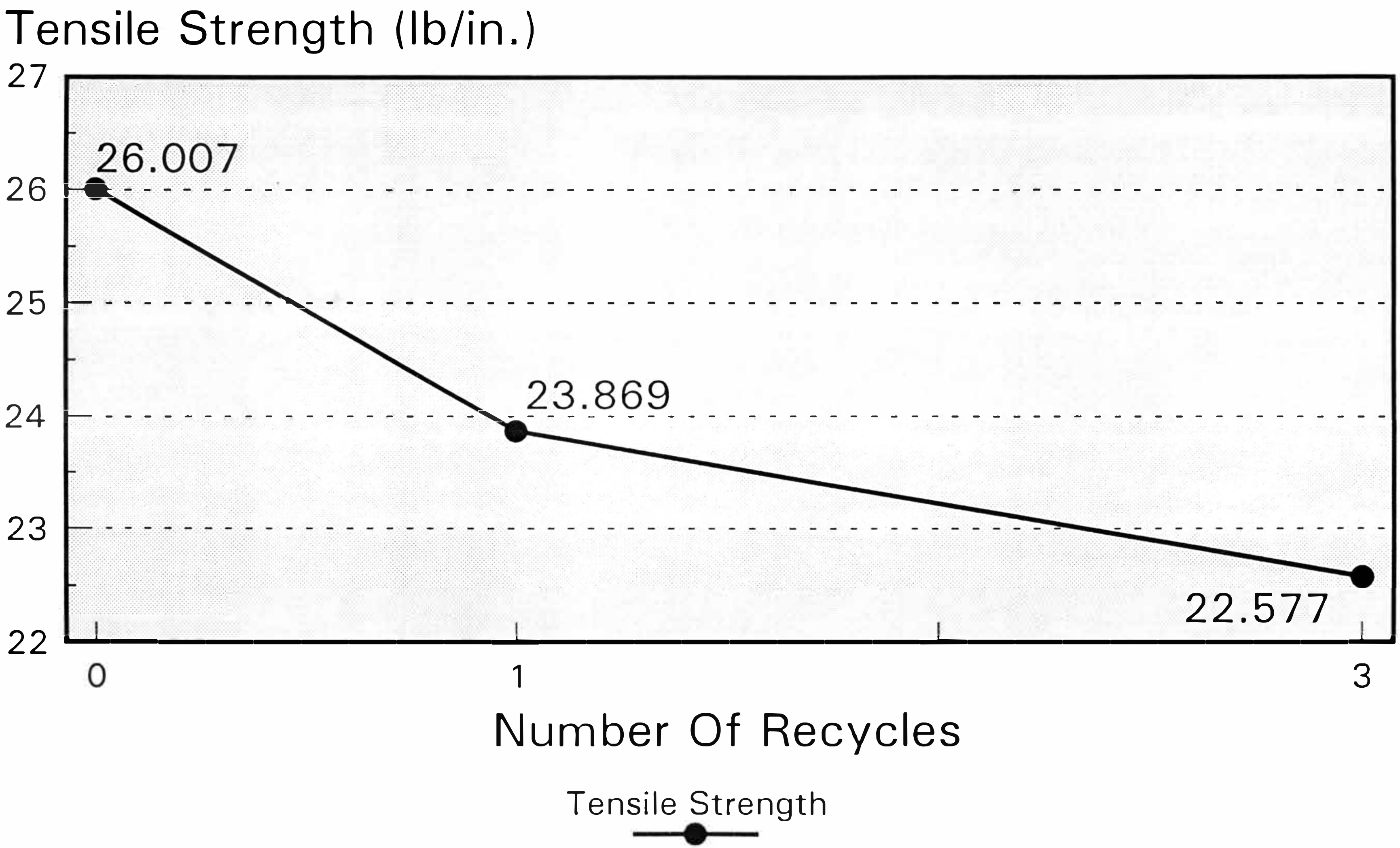


FIGURE 6: THE EFFECT OF THRICE-DRIED FINES ON THE TENSILE OF DIFFERENT LONG FIBER COMPONENTS

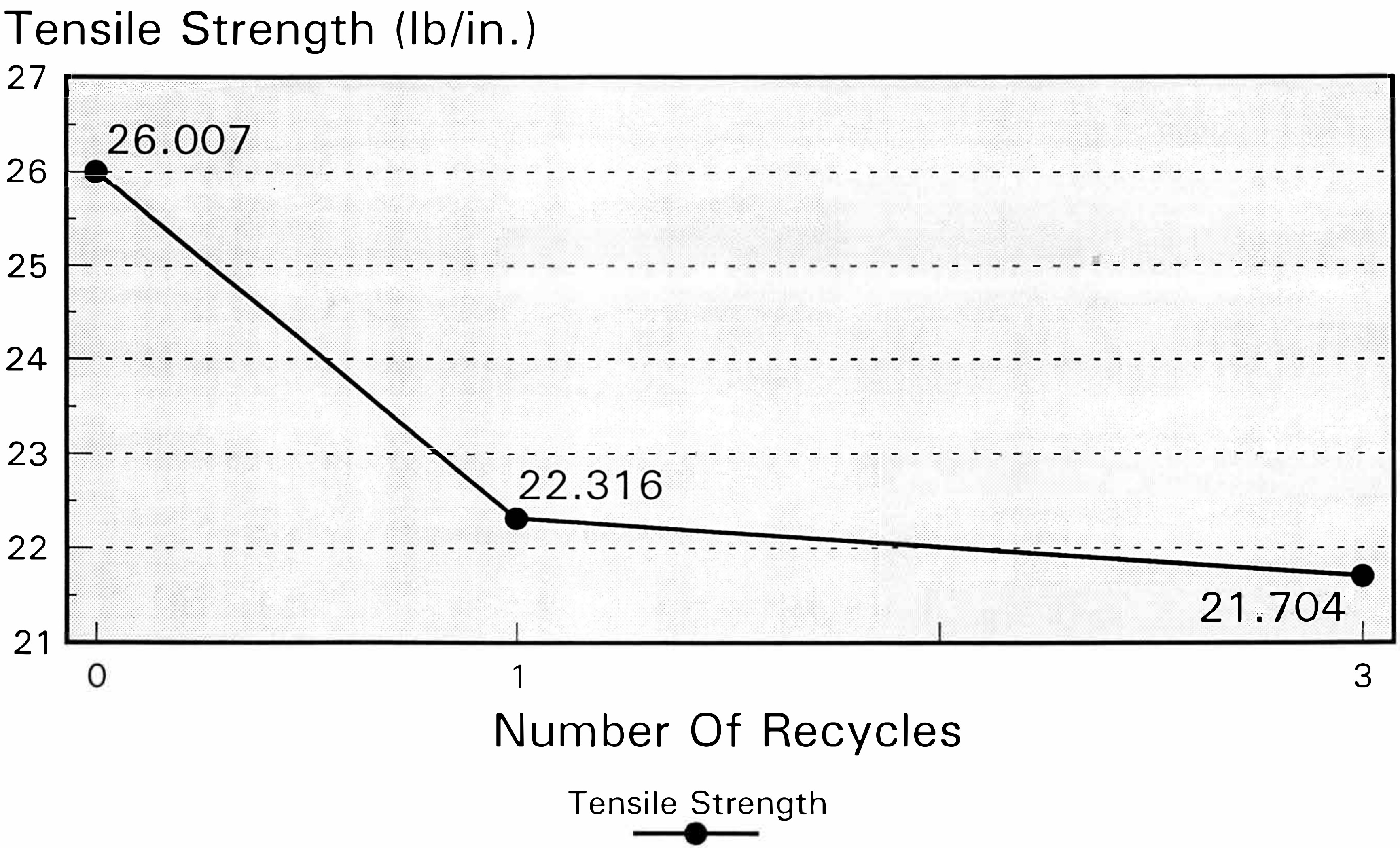


FIGURE 7: A COMPARISON OF THE EFFECT OF FINES ADDITION ON THE TENSILE OF LONG FIBERS

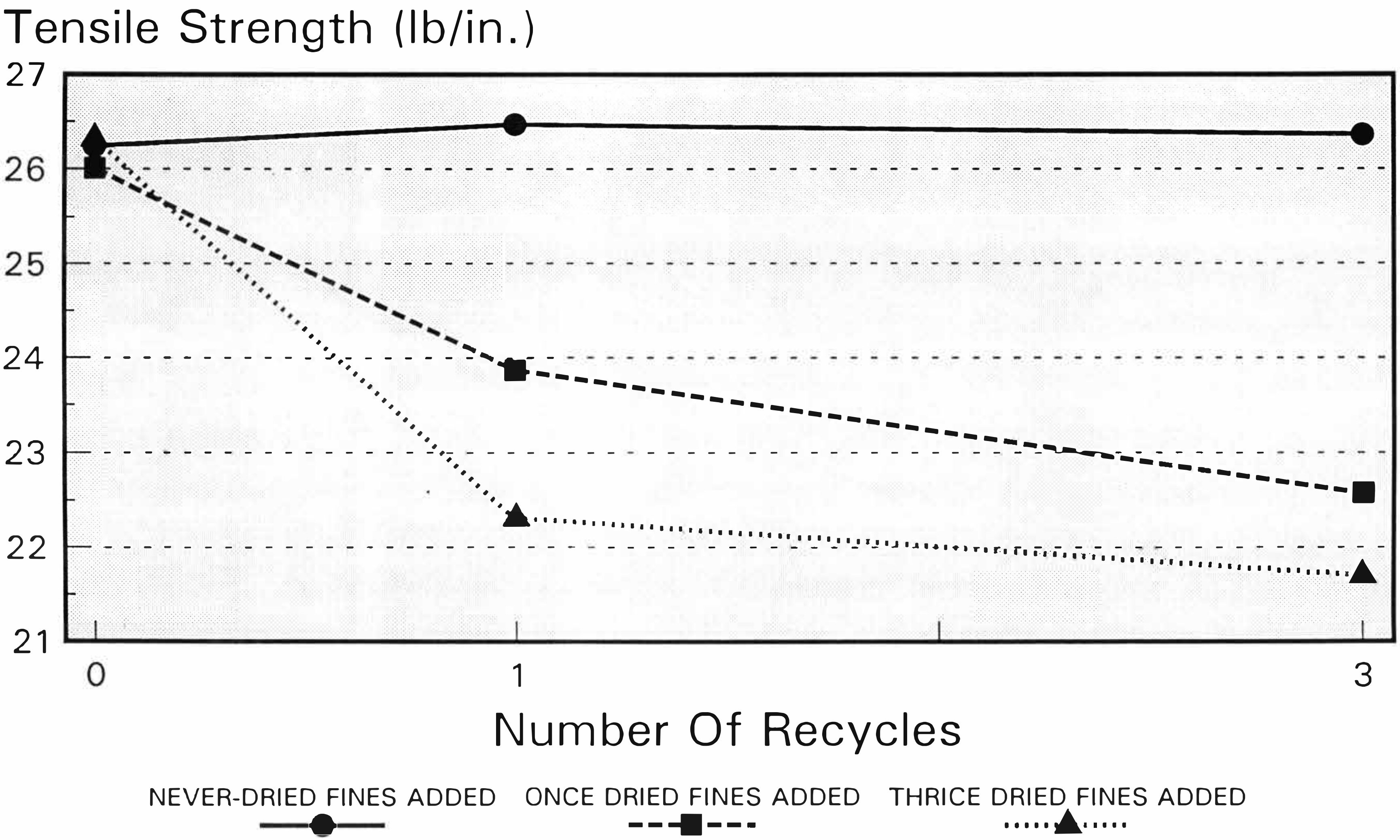


FIGURE 8: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET BURST STRENGTH

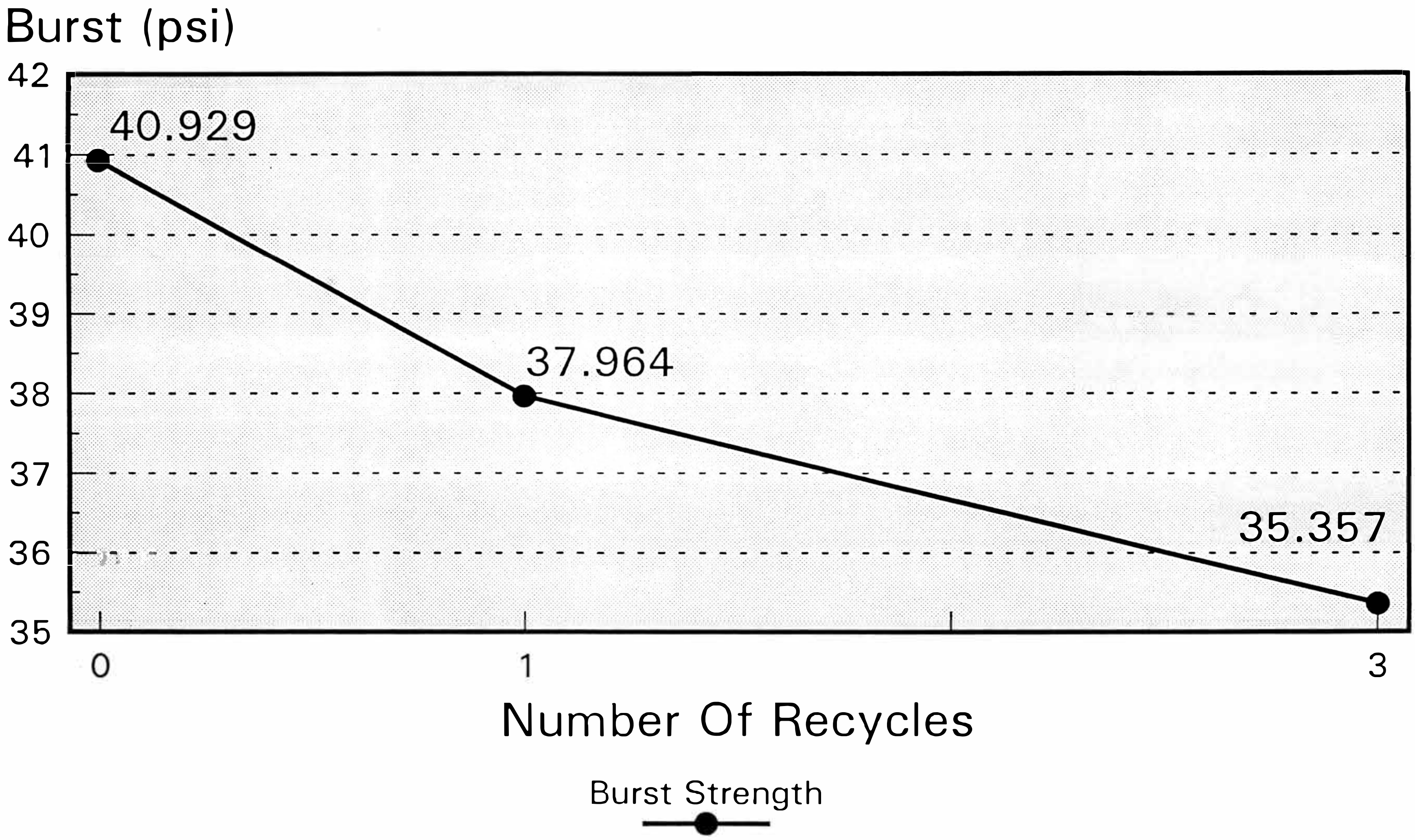


FIGURE 9: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET BURST STRENGTH

****LONG FIBERS ONLY****

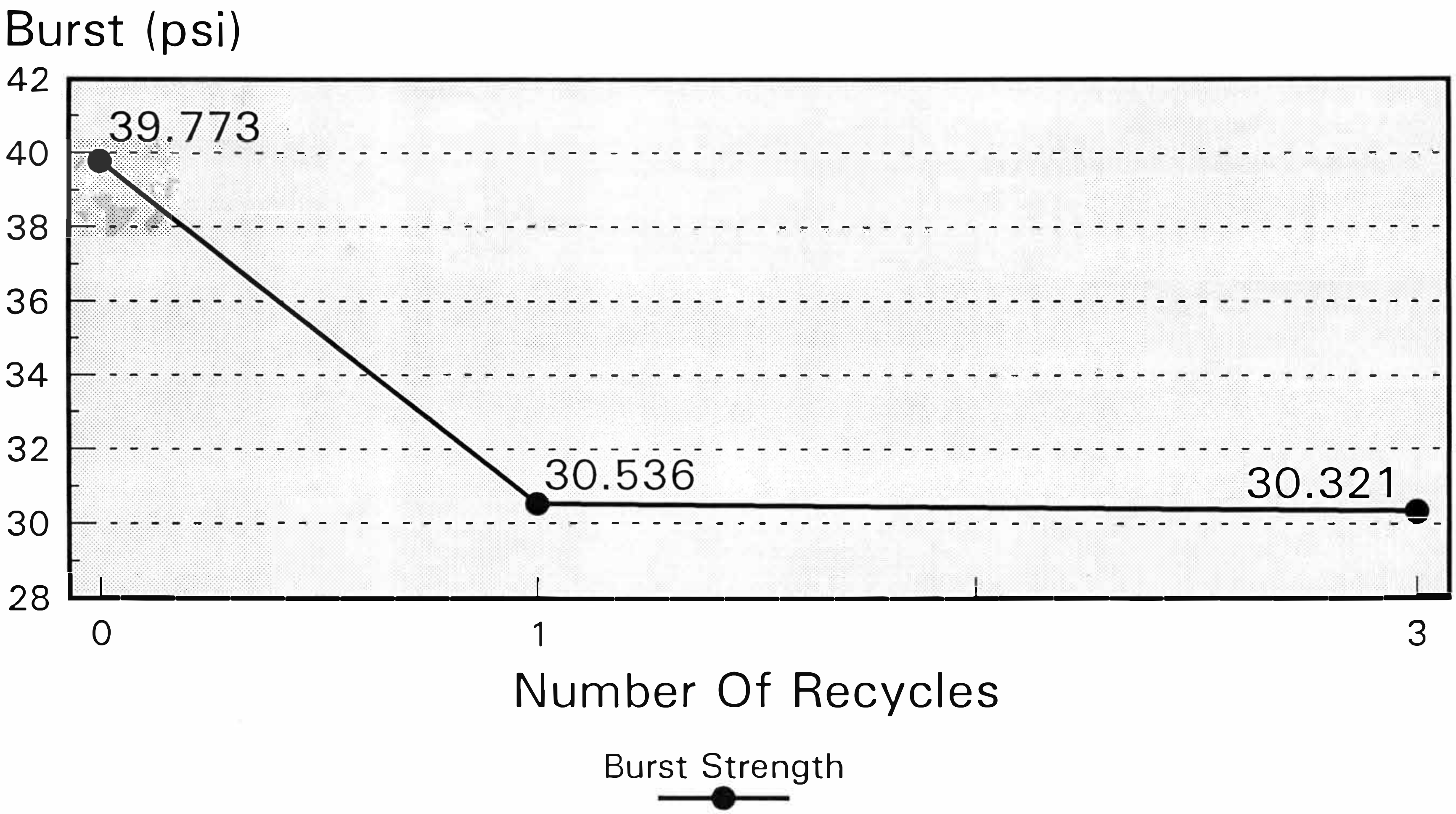


FIGURE 10: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET BURST STRENGTH

SCREENED vs. UNSCREENED

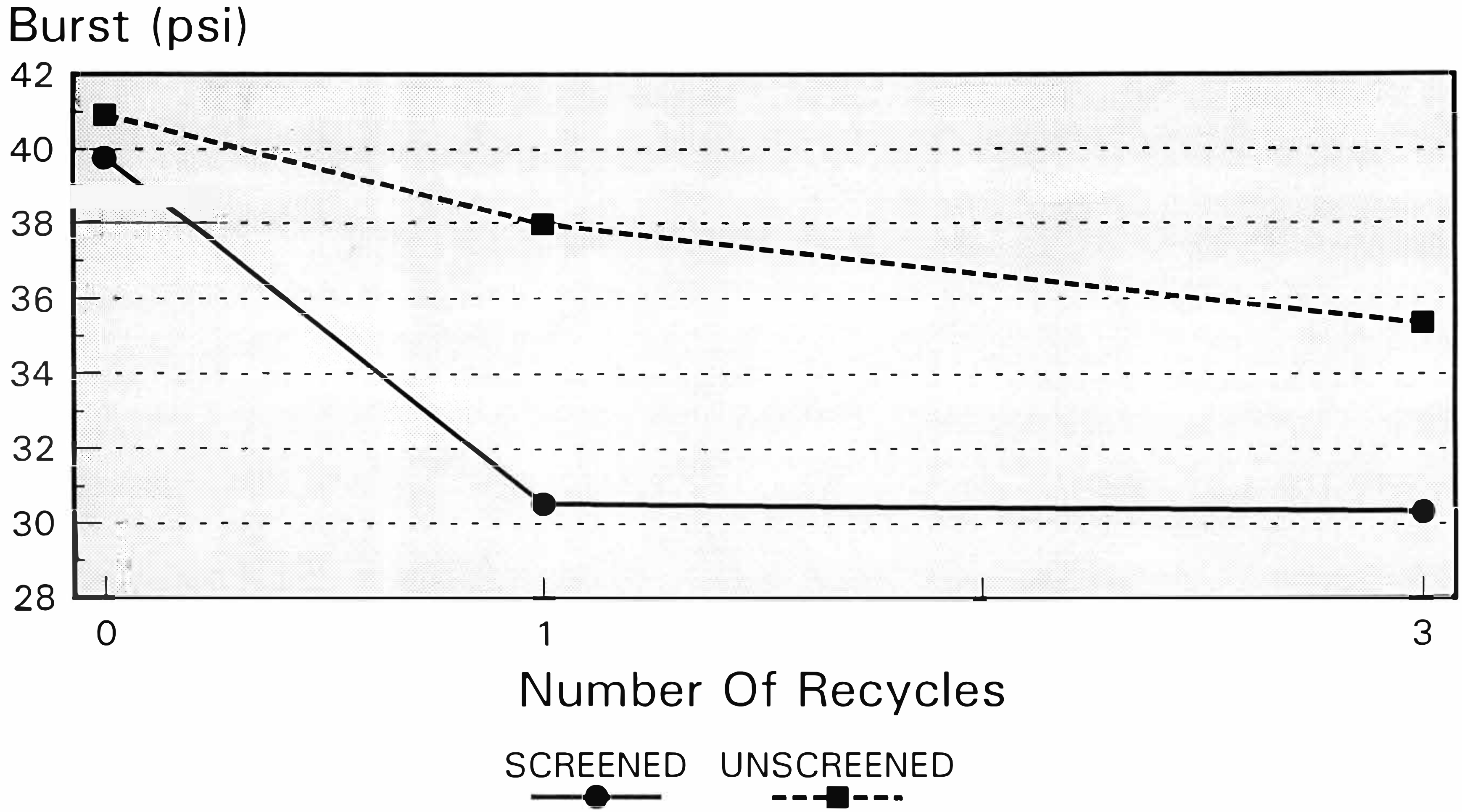


FIGURE 11: THE EFFECT OF NEVER-DRIED FINES ON THE BURST OF DIFFERENT LONG FIBER COMPONENTS

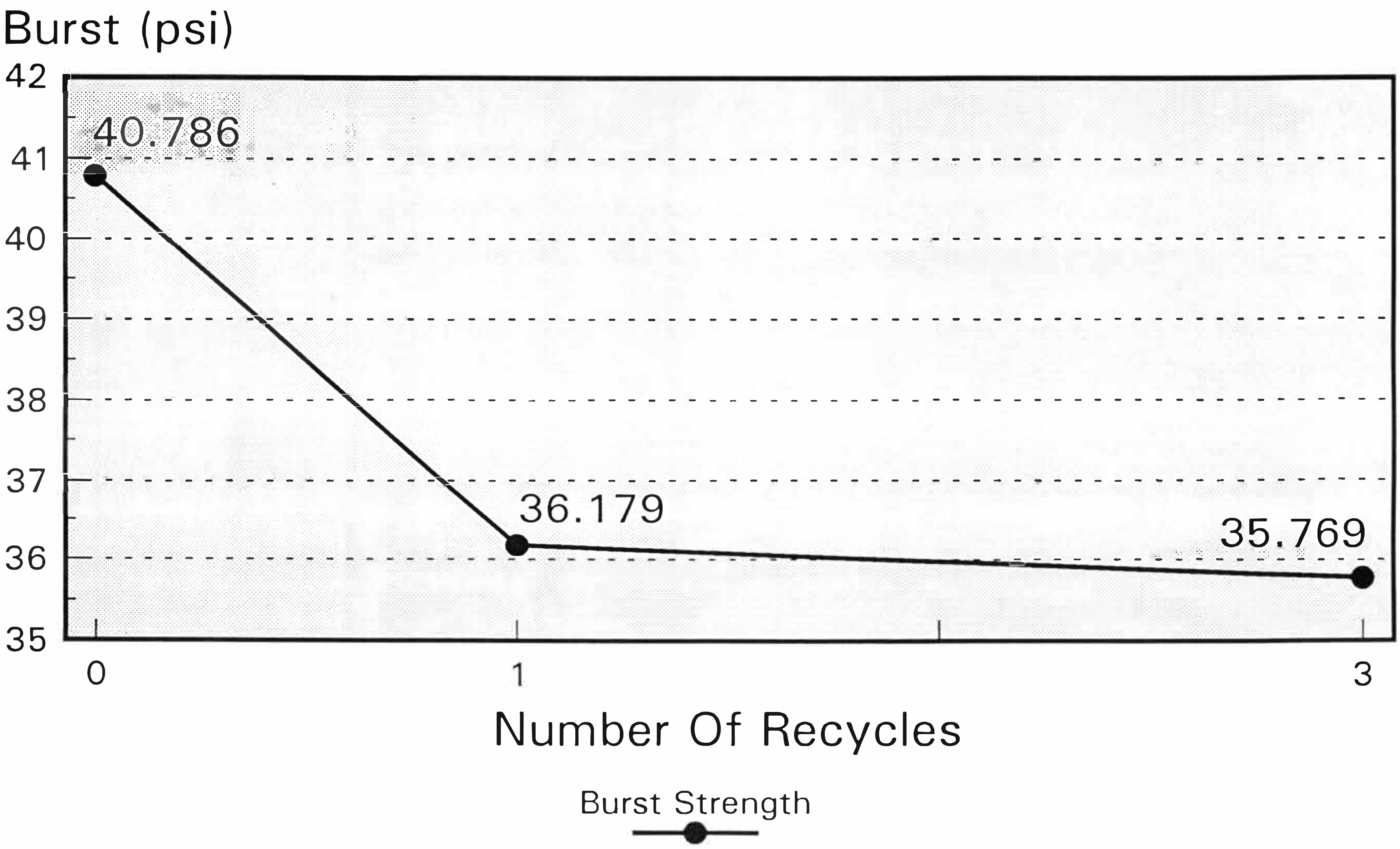


FIGURE 12: THE EFFECT OF ONCE-DRIED FINES ON THE BURST OF DIFFERENT LONG FIBER COMPONENTS

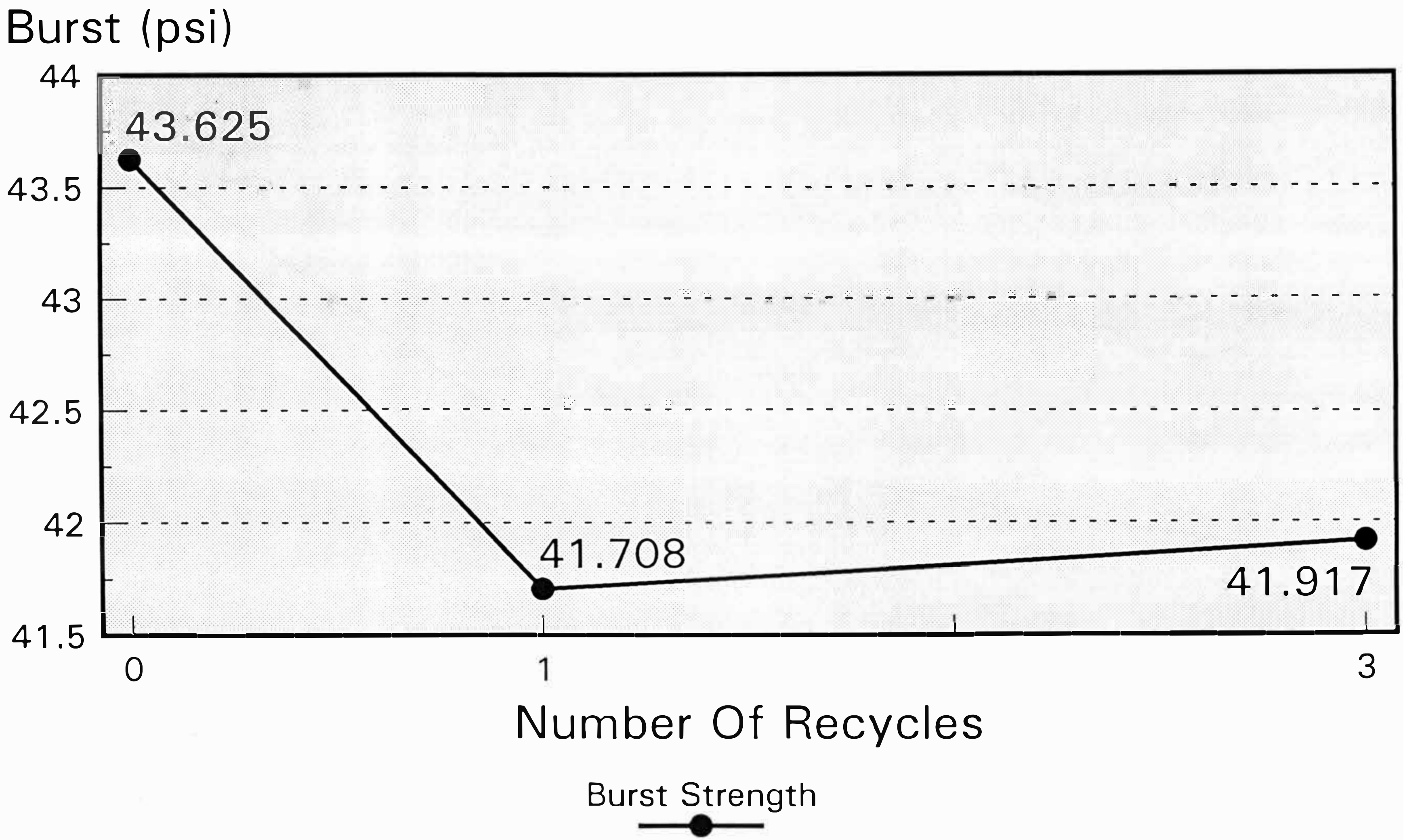


FIGURE 13: THE EFFECT OF THRICE-DRIED FINES ON THE BURST OF DIFFERENT LONG FIBER COMPONENTS

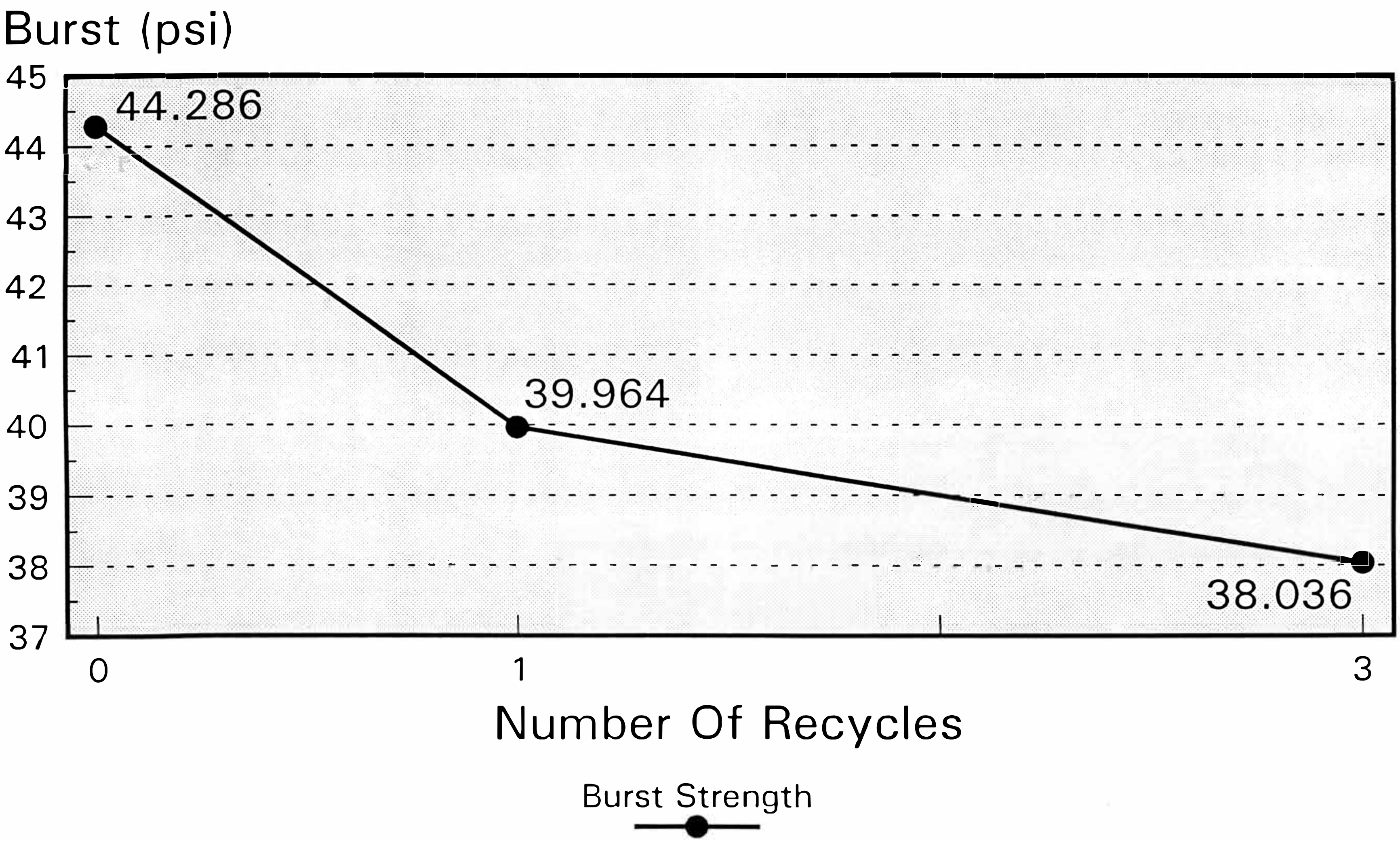


FIGURE 14: A COMPARISON OF THE EFFECT OF FINES ADDITION ON THE BURST OF LONG FIBER COMPONENTS

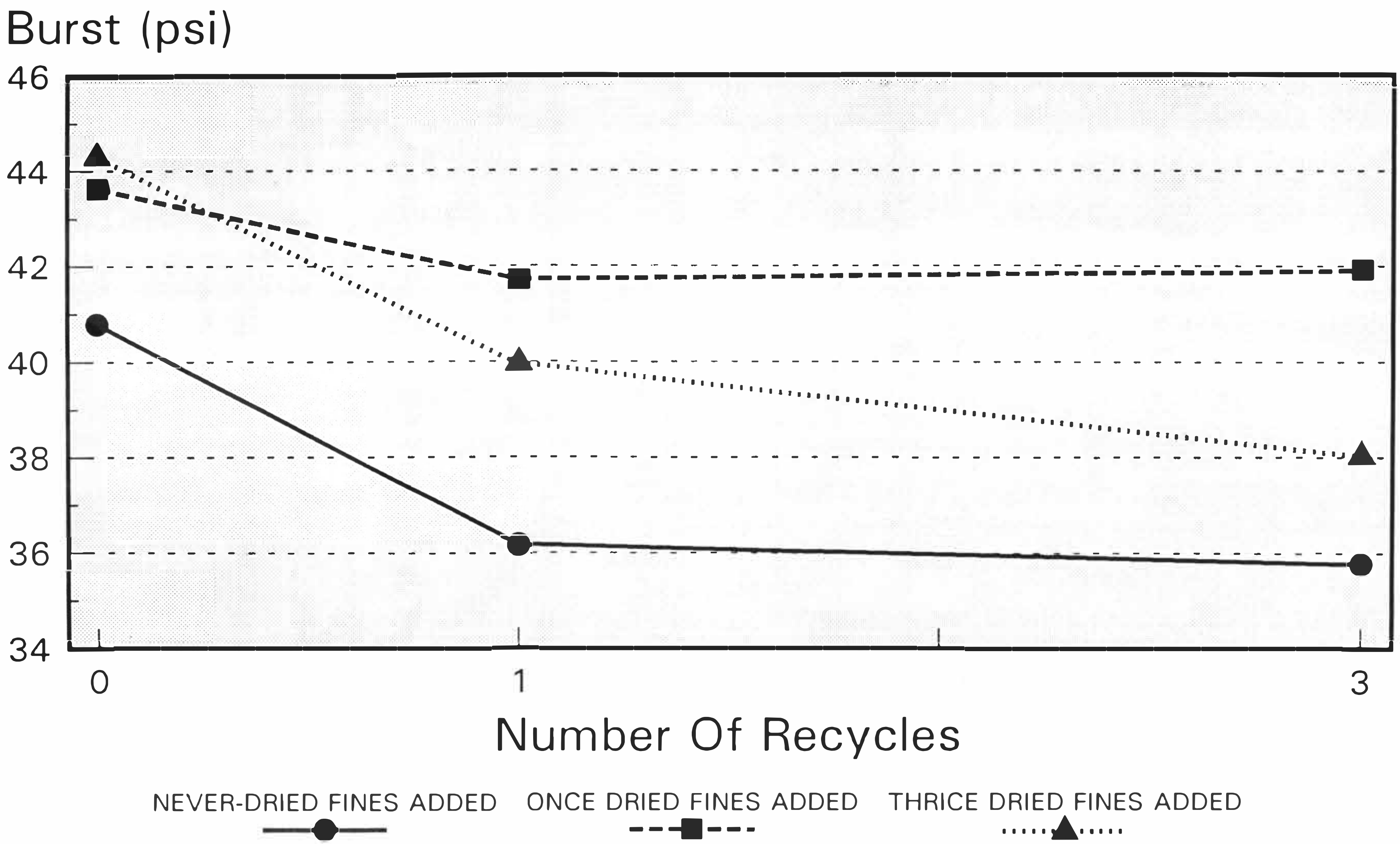


FIGURE 15: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET SCOTT BOND

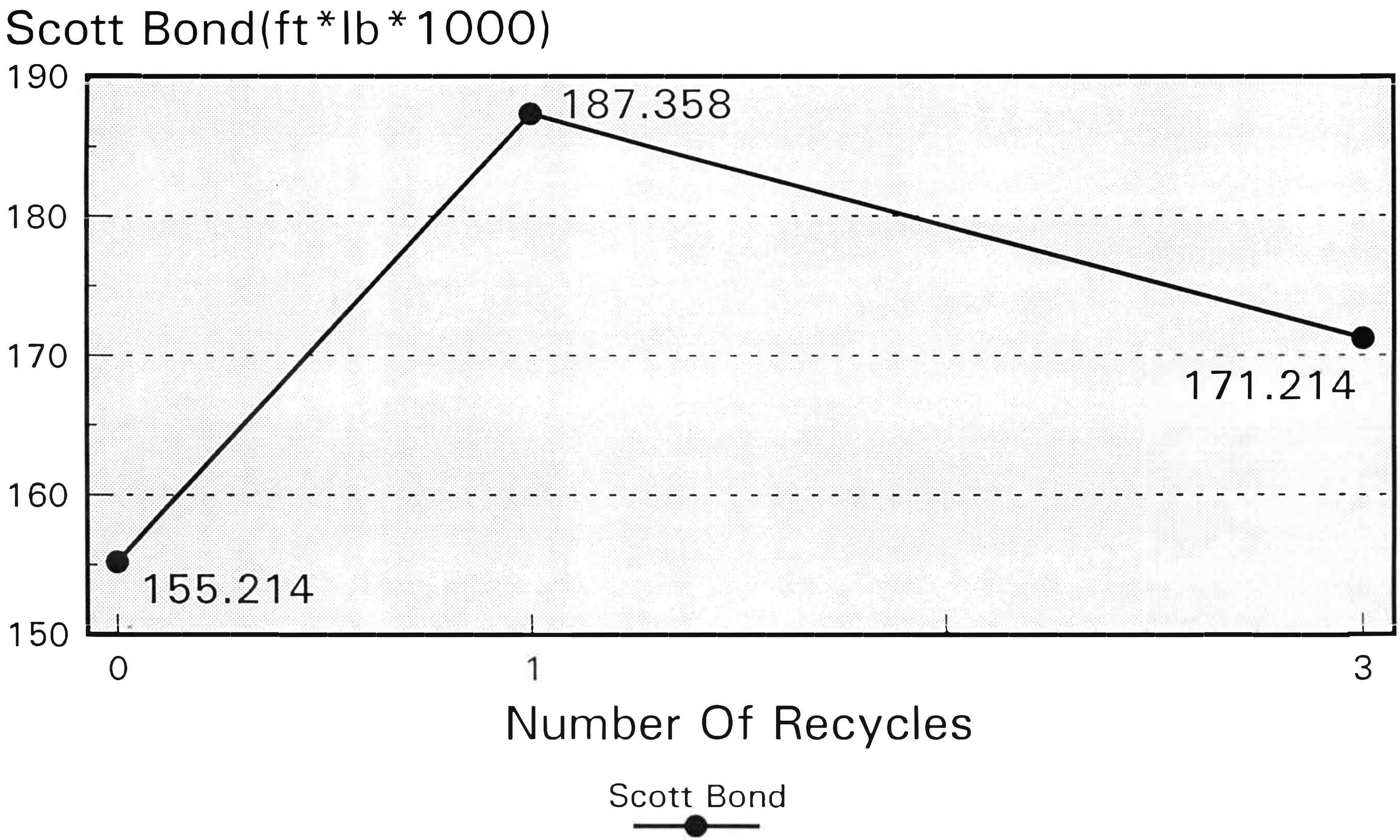


FIGURE 16: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET SCOTT BOND

LONG FIBERS ONLY

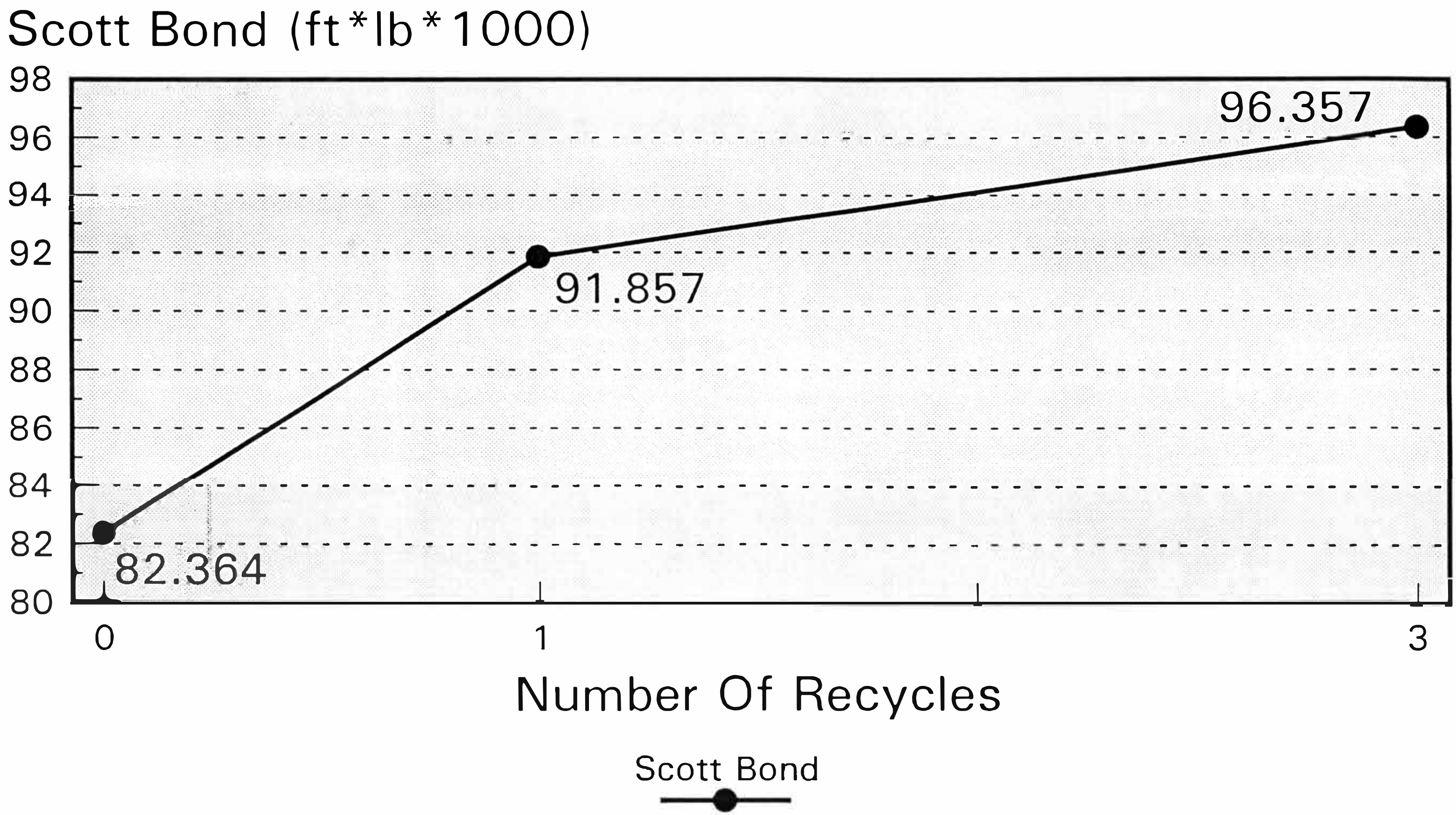


FIGURE 17: THE EFFECT OF ZERO, ONE, AND THREE RECYCLES ON HANDSHEET SCOTT BOND

SCREENED vs. UNSCREENED

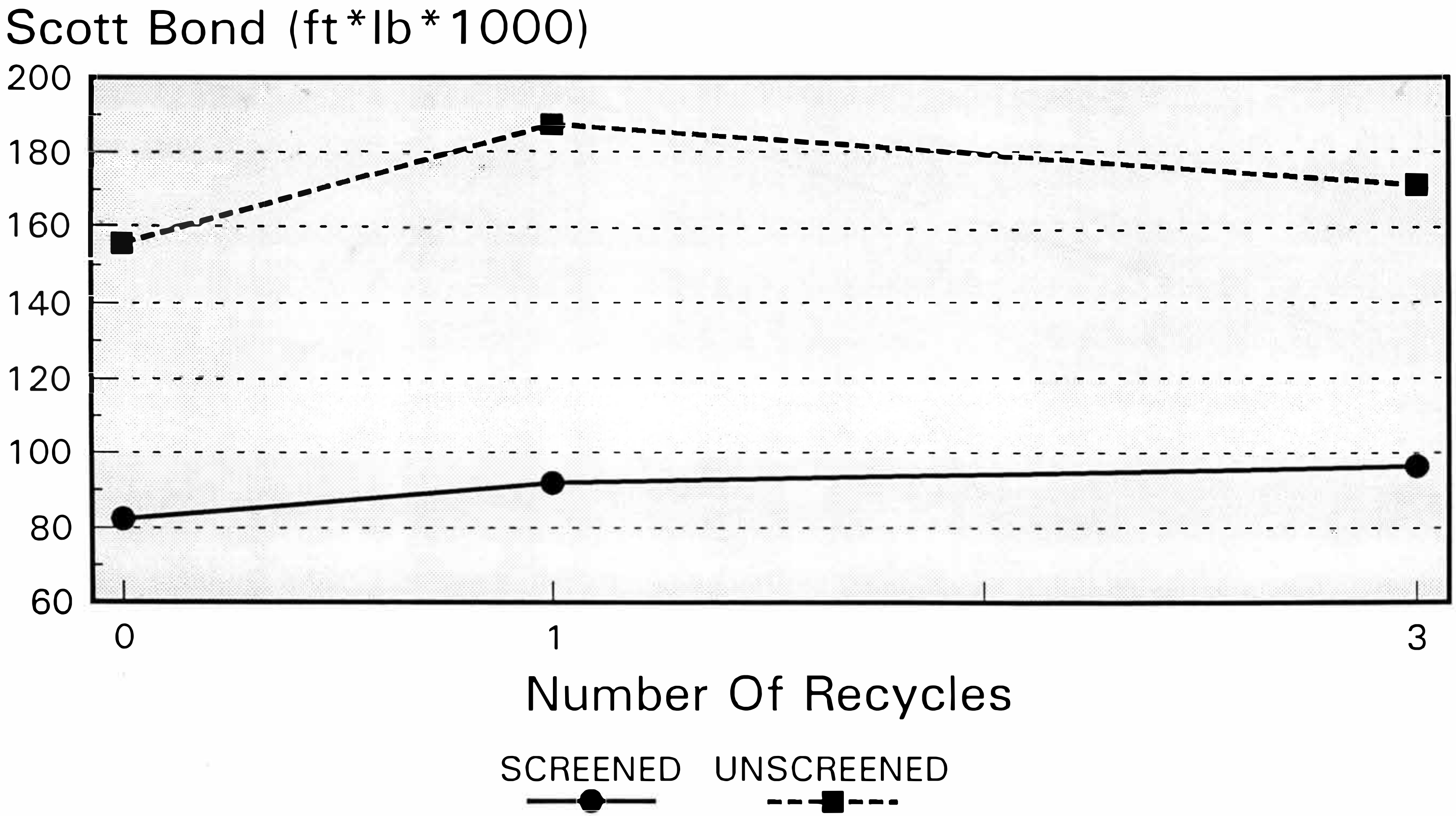


FIGURE 18: THE EFFECT OF NEVER-DRIED FINES ADDITION ON THE SCOTT BOND OF LONG FIBERS

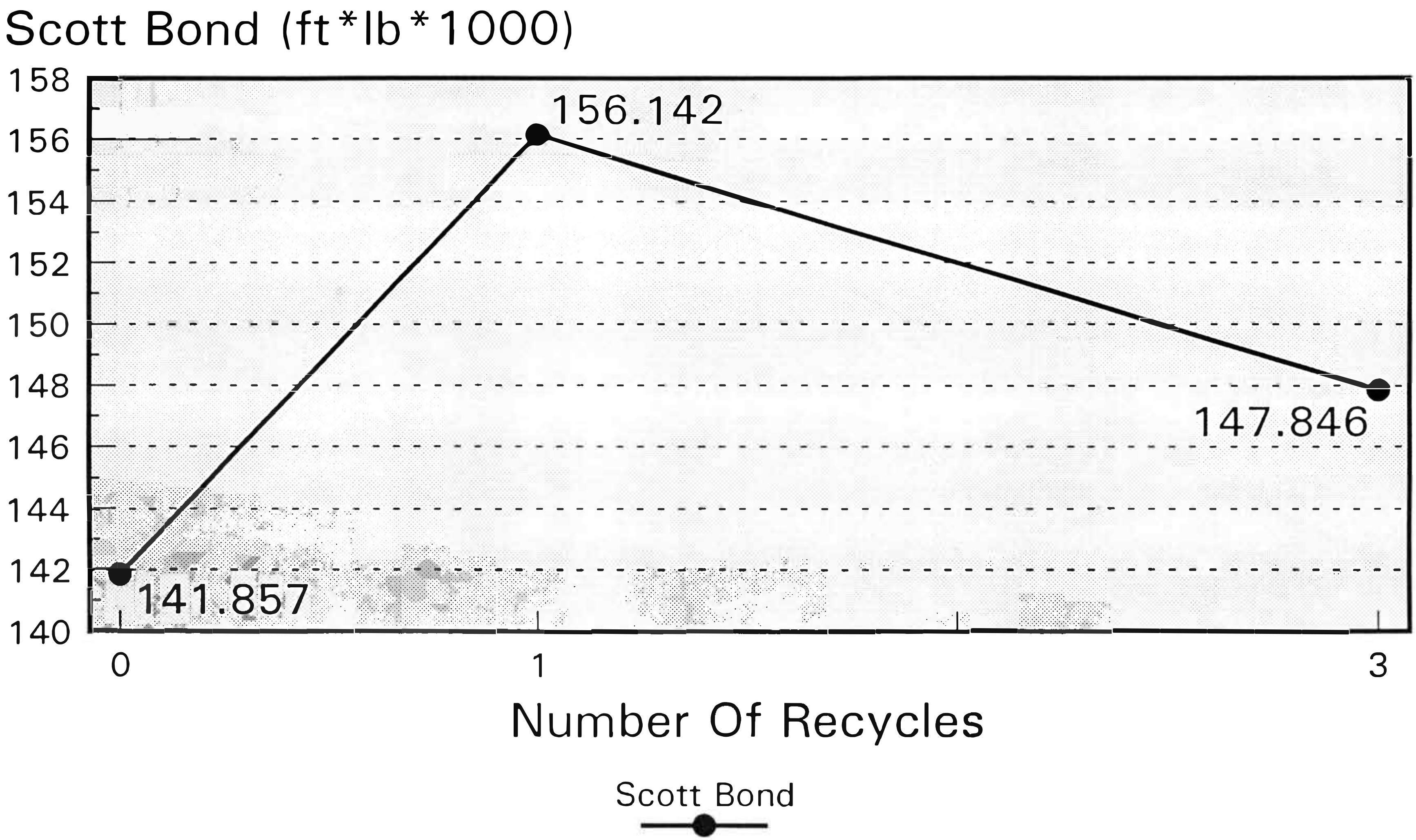


FIGURE 19: THE EFFECT OF ONCE-DRIED FINES ADDITION ON THE SCOTT BOND OF LONG FIBERS

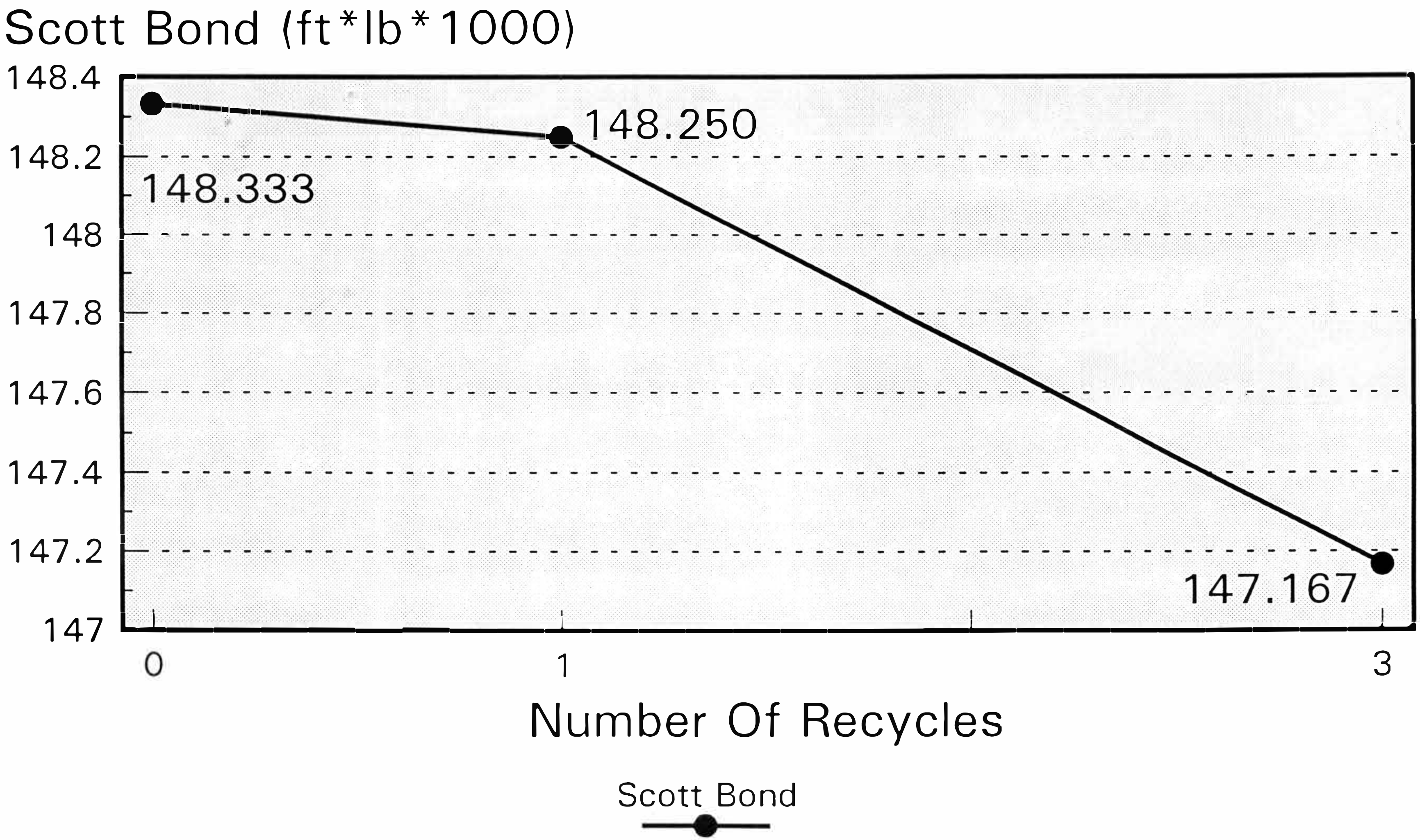


FIGURE 20: THE EFFECT OF THRICE-DRIED FINES ADDITION ON THE SCOTT BOND OF LONG FIBERS

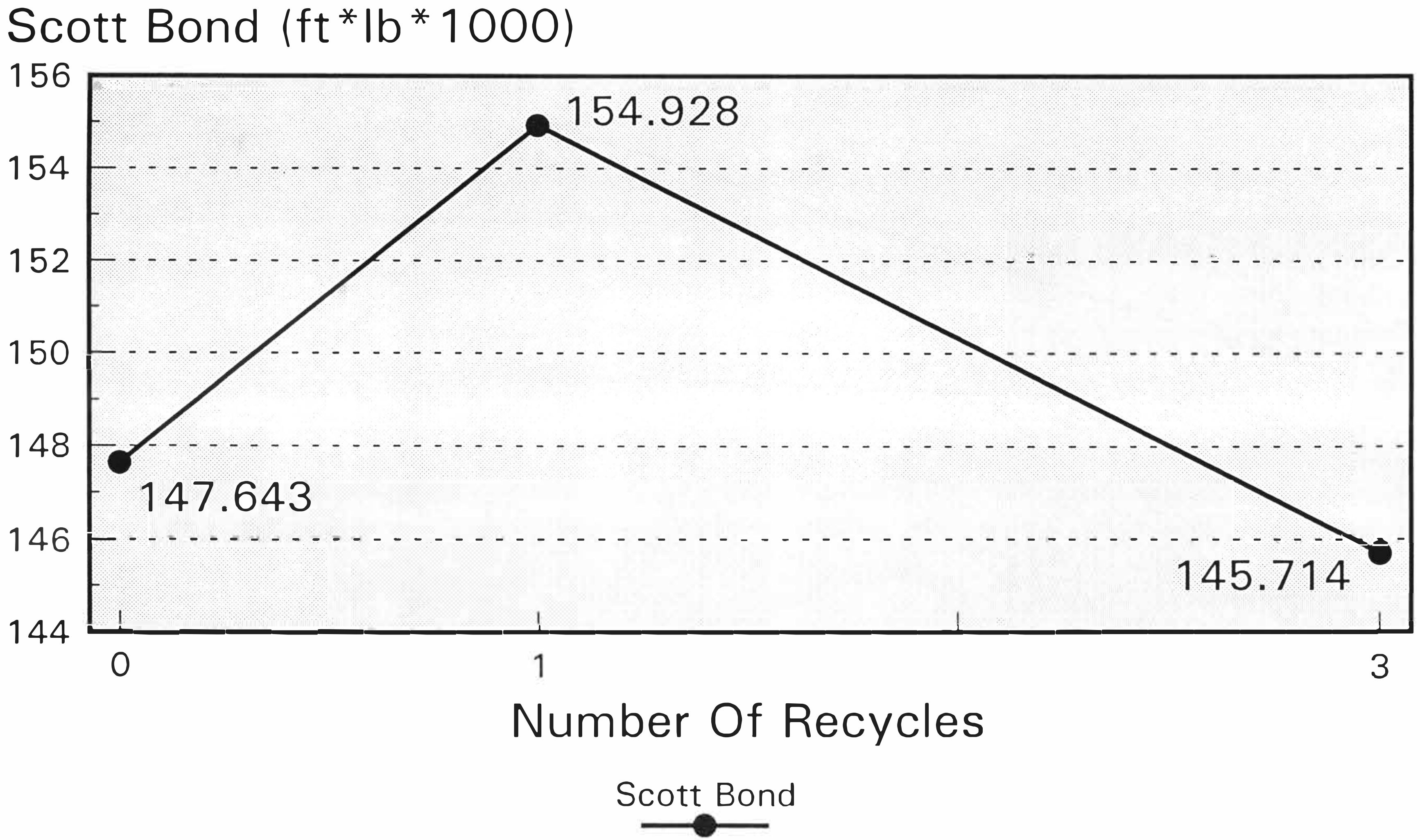
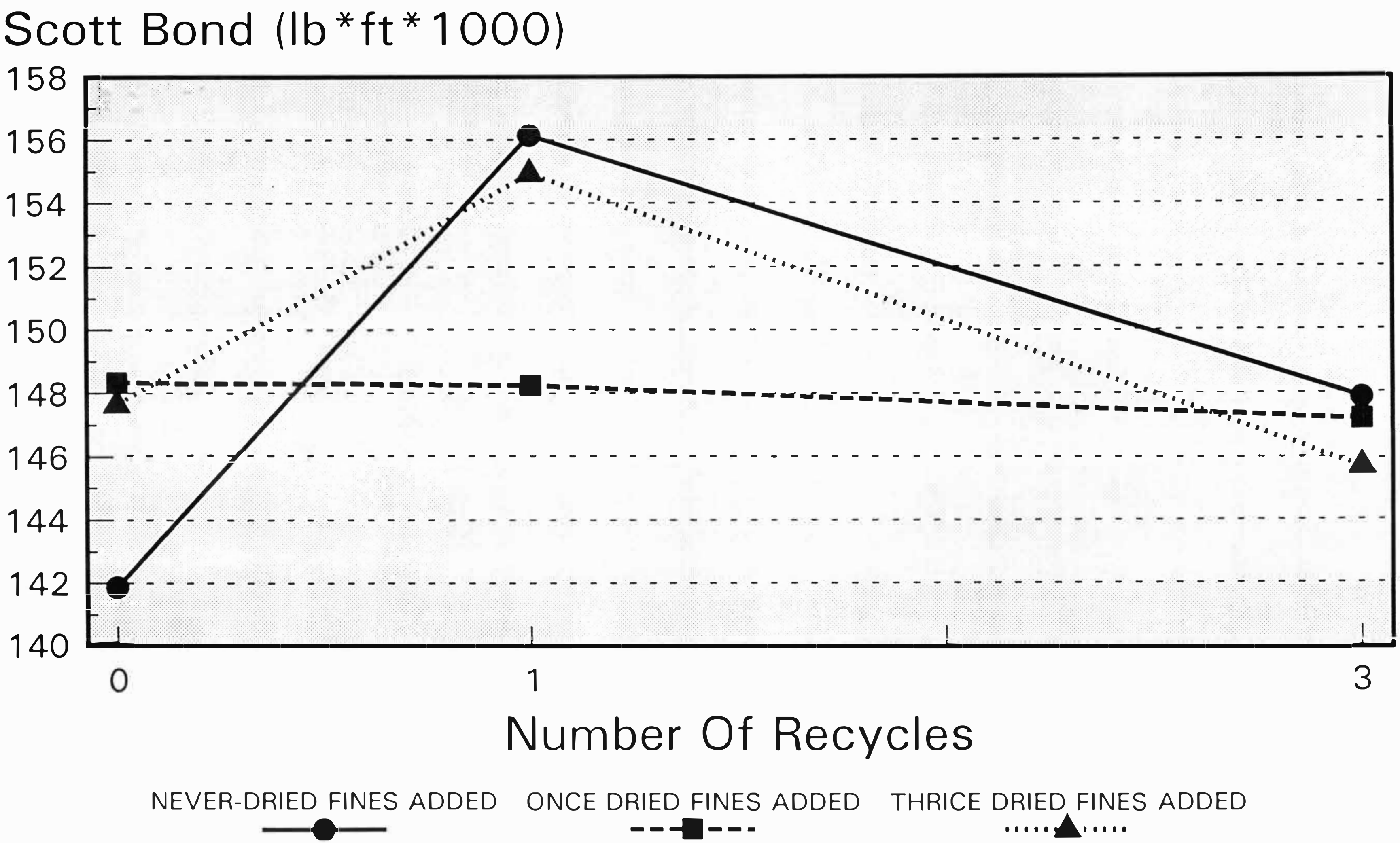


FIGURE 21: A COMPARISON OF THE EFFECT OF FINES ADDITION ON THE SCOTT BOND OF LONG FIBERS



DISCUSSION OF RESULTS

Figures 1 - 7 deal with effect of the different fine / long fiber mixtures on tensile strength. The numbers obtained for the tensile strength, %stretch, and tensile energy absorption can be seen in Appendix I. This report will only analyze the tensile strength data because of its direct relation to the other two. Tensile strength is defined as the maximum tensile stress developed in a test specimen before rupture in a tensile test carried to rupture under prescribed conditions. Tensile strength is the force per unit width of test specimen; (Tappi standard 494 om-88), in this case lbf / inch.

Figure 1 shows the effect of zero, one, and three recycles on handsheet tensile strength. This was done on the three fiber groups before any screening, to show the strength of the paper conventionally made. The graph shows a definite downward trend that is expected with each recycle. From the literature collected for this report, it is expected that this graph should be concave up instead of concave down, and would eventually level out. This leveling out phase, however, would not occur until after 5 or 6 recycles. It can also be seen that a more dramatic drop occurs at the third recycle. Figure 2 shows the effect of zero, one and three recycles on handsheet strength of the screened long fibers. These fibers have been screened once for fines and once to ensure the purity of the long fiber component. This graph shows more of the expected trend, concave up, and possibly flattening out. The most important observation becomes apparent when Figures 1 and 2 are combined to form Figure 3. This figure shows the difference that having fines in the sheet makes to the tensile strength. At never-dried, the values for the screened vs. the unscreened is fairly small. However, at 1 and 3 recycles, the gap between these values begins to grow. It is known that the long fiber component is the most important to tensile strength, but this figure shows that the fines can also play a role by helping to strengthen the bonds between the long fibers.

Figure 4 shows the effect of adding never-dried fines to the screened long fibers from 0, 1, and 3 recycles. The rise and fall of this graph can be overlooked because of the fact that each represents a change of less that 1%. The important trend from this graph is that the never-dried fines kept the tensile strength from dropping as expected. This shows that the never-dried fines have great bonding ability, even to the thrice recycled long fibers. Figure 5 shows the effect of adding once dried fine to the screened long fibers from 0, 1, and 3 recycles. This figure shows the trend of the tensile dropping with each recycle, however, the change is not nearly as great as that seen in Figure 2 which shows the tensile value dropping below 17 after 3 recycles. Figure 6 shows the effect of adding thrice-dried fines to the screened long fibers from 0, 1, and 3 recycles. This graph shows the expected downward, concave up curve. By comparing this to Figure 2, it can be seen that even thrice dried fines are not as detrimental to the tensile as not having them.

Figure 7 shows the comparison of adding never-dried, once-dried, and thrice dried fines to the screened long fibers from 0, 1, and 3 recycles. This graph shows that the tensile decreases from the use of never-dried to once-dried, and again to thrice dried. It can be taken from this result that the experiment could have been carried out further, in order to find the point at which fines become detrimental to the tensile strength. Even the thrice recycled fines give higher values than the sheets made with just long fibers. It appears that without any fines, the long fibers do not have enough bonding surface area to make the sheet strong, even if the boning surface is stronger.

Figures 8 - 14 show the effect of deal with the effect of different long fiber / fine combinations on burst strength. Bursting strength is defined as the hydrostatic pressure required to produce rupture of the material when the pressure is increased at a controlled constant rate through a rubber diaphragm to a circular area (Tappi standard 403 om-91).

Figure 8 shows the effect of 0, 1, an 3 recycles on hansheet burst strength. This was done on each of the three fiber groups before any screening. This graph shows the concave up, downward trend that is expected. The burst value would also be expected to level out at around 5 or 6 recycles, with the most dramatic drops occurring between the first couple recycles. Figure 9 shows the effect 0, 1, and 3 recycles on the screened long fibers from each grouping. This graph shows a large drop in burst due to the first recycle, and almost leveling off after it. It is suspected from other data, that this value would not drop much lower since at this point it has already decreased by 20%. Figure 10 shows the comparison of burst reduction due to recycling of the screened and unscreened fibers; a combination of Figures 8 and 9. Similar to the tensile comparison, this graph shows fines to have a positive effect on burst. The values of the never-dried screened and unscreened are fairly close to one another, with the screened long fibers showing a more dramatic drop at 1 recycle.

Figure 11 shows the effect of adding never-dried fines to never-dried, once recycled and thrice recycled long fibers. The curve appears to have the same curve as the screened long fibers in Figure 9, except that it levels out about 5 points higher. This shows the never-dried fibers to have a positive effect on burst for all three recycle stages. Figure 12 shows the effect of adding once dried fines to the different long fiber components. It appears that this curve is also leveling out at 3 recycles. However, it levels out around 6 points higher than the same run with never-dried fines. Figure 13 shows the effect of adding thrice dried fines to the different long fiber components. This graph follows the trend of the previous two, seeming to start leveling out at the third recycle. The most interesting question is posed when these three curves are combined in Figure 14, which shows never-dried, once-dried, and thrice-dried fines added to the long fiber components. This graph shows that the sheets made with never-dried fines had a lower bursting strength than once-dried and the thrice-dried. Apparently, the once-dried fines have the right combination of bonding ability, strength, and possibly charge and agglomeration ability to make a stronger sheet than the never-dried fines. It would be easy to question this data except for the fact that the thrice-dried fines also gave higher values, the difference being that the thrice-dried line on this graph appears to be dropping faster. By comparing this graph with that of Figure 10, it can be seen that never-dried fines have a negative effect on the burst after one recycle and the thrice-dried fines become detrimental after the third recycle. If this experiment would have been carried out another step, to four or five recycles, it is suspected that the fines strength would drop off.

Figures 15 - 21 deal with the effect of different fines / fiber combinations on Scott Bond. The Scott Bond test is explained in Appendix III. This test is used to determine the strength of the internal bonds of the sheet, and shows the importance of fines the most out of the three tests run on the handsheets.

Figure 15 shows the effect of 0, 1, and 3 recycles on the Scott Bond of handsheets made of the different pulp samples before being screened. This graph shows the internal bond strength after one recycle to increase and then begins to drop off. During the literature search for this experiment no information on the effect of bonding strength was found, but I feel that this test is important to show the full effect of fines. Figure 16 shows the effect of 0, 1, and 3 recycles on the Scott Bond of handsheets made of the already screened long fiber components. Without the fines in the sheet the Scott Bond values increase for both the first and third recycle. The curve begins to flatten after the first recycle and it suspected that it will begin to fall soon after the third recycle. It can be speculated that the long fibers still maintain surface bonding activity, and are strengthened by their increased crystallinity and stiffness. Figure 17 shows the comparison of the screened long fibers and the unscreened original components. As stated before, this test shows the importance of fines to bonding strength in the early stages of recycling. The values of the sheets containing fines are two times larger than the values obtained from the screened long fibers. This again shows the increased bonding area that fines provide to help strengthen the sheet.

Figure 18 shows the effect of adding never-dried fines on the Scott Bond of the different long fiber components. As with the unscreened long fibers, this curve also peaks at the one recycle before beginning to fall. Figure 19 shows gives a different trend when once-dried fines are added to the three long fiber components. This curve does not peak at one recycle, but only falls a tenth of a point. The third recycle does, however, begin a steeper downward trend. Figure 20 shows the effect of adding thrice-dried fines on the

Scott Bond of the three long fiber components. The curve of this graph also peaks at one recycle, before it begins to fall rapidly to the third. This curve reinforces the fact that the stiffness obtained from one recycle combined with the remaining surface activity creates a stronger paper before the stiffness increase and bonding ability decrease become dominant in the internal bonding mechanism. Figure 21 shows the comparison of the effect of never-dried, once-dried, and thrice-dried fines are added to 0, 1, and 3 times recycled long fiber. The most important information to be gathered from this plot can be gained by comparing it to Figure 17. By doing this, it can be seen that the unscreened fiber mixture has higher values than any of the fiber / fine mixtures. This is due to the fact that the unscreened mixture has a more well rounded fiber length distribution, allowing the sheet to be denser and have more bonding surface area.

These results as a whole show that the industry may be dealing with strength loss in recycled paper in the wrong way. Currently, long fibers are added in many applications in order to bring the strength of the paper up. It may, in fact, be the bonding of the fines that are added along with the long fiber that increase the strength. This study has shown the large surface area and appatrently very active surfaces of fines can increase the strength of paper, even after being recycled.

It is possible that the paper industry is not dealing with the strength loss of recycled fiber correctly. It is currently common practice to add long fibers to the stock for strength improvement. This project has proven that much better results could be gained by adding never-dried fines that will act like a glue and strengthen the sheet.

CONCLUSIONS

It can be concluded from Figures 3, 10, and 17 that never-dried, once-dried, and thrice-dried fines all increase the following strength properties: Tensile, burst, an Scott Bond.

It has also been shown that tensile strength can be kept from dropping at one and three recycles by adding never dried fines. Once-dried fines and thrice-dried fines both cause the tensile strength to fall more rapidly than it would without them. This shows that fines begin losing their bonding ability immediately and become detrimental to the strength of the sheet.

Once-dried fines were found to have the best effect of burst strength, followed by thrice-dried fines; with the never-dried fines having a negative effect on burst. This data must be deemed as suspect due to the fact that no previous resaech can support it.

Fines were found to be the most important to the internal bond strength, tested using Scott Bond. The screened long fibers registered values half of those put up by the sheets containing fines. Scott Bond was shown to peak after one recycle, and then begin to fall rapidly.

Virgin fines should be added to recycled stck to increase the strength, and not long fiber; the current trend in the industry.

RECOMMENDATIONS

The main recommendation that I have to make on this experiment and how it ran is the fact that the point at which the fines become detrimental to all strength was not reached. It can be proposed that the downward trends would continue to a detrimental point, but it would have been great to have that point recognized. If this experiment would have been done so that 4, 5, 6, 7, and 8 times recycled fines were collected; a true point of crystallinity and limited bonding ability would have been recognized. This projects resuts also raise the big question about hardwood fines: Would they too increase the sheet strength in the same way and by the same magnitude.

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8) Britt, K. W. Fractionation on paper machine systems." Tappi Journal, September 1986. Vol. 68, No. 9. pp. 114-17

Appendix I

Kajaani Results

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE NDL
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	0.31	I
0.20	1.14	+
0.41	3.09	-+-
0.61	4.48	--+-
0.82	5.11	---+-
1.02	5.26	----+
1.23	5.29	----- I
1.44	4.83	---- I
1.64	4.48	---- I
1.85	4.60	---- I
2.05	4.88	---- I
2.26	4.79	---- I
2.47	4.27	---- I
2.67	3.67	--- I
2.88	3.66	--- I
3.08	3.61	--- I
3.29	3.87	--- I
3.50	3.39	--- I
3.70	2.82	-- I
3.91	2.06	-- I
4.11	2.07	-- I
4.32	1.84	- I
4.52	1.70	- I
4.73	1.45	- I
4.94	1.42	- I
5.14	1.25	- I
5.35	1.16	- I
5.55	0.80	I
5.76	0.57	I
5.97	0.38	I
6.17	0.45	I
6.38	2.07	-- I
6.58	3.73	--- I
6.79	5.50	----- I
--->	1.14	- I

CHARACTERISTICS
TOTAL FIBERS 6479

CHAR	WEIGHTED		ARITHMETIC
D1	0.66		0.00
Q1	1.25		0.14
Q2	2.35		0.62
Q3	3.85		1.55
D9	6.31		2.93
AV	2.79	4.06	1.33

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE NDL
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	16.79	----+-----------
0.20	12.29	---------+----
0.41	11.11	----------+
0.61	9.68	--------- I
0.82	7.88	------- I
1.02	6.31	------ I
1.23	5.19	----- I
1.44	4.01	---- I
1.64	3.23	--- I
1.85	2.92	-- I
2.05	2.77	-- I
2.26	2.47	-- I
2.47	2.00	- I
2.67	1.58	- I
2.88	1.46	- I
3.08	1.35	- I
3.29	1.35	- I
3.50	1.11	- I
3.70	0.87	I
3.91	0.60	I
4.11	0.57	I
4.32	0.49	I
4.52	0.47	I
4.73	0.35	I
4.94	0.33	I
5.14	0.28	I
5.35	0.25	I
5.55	0.16	I
5.76	0.11	I
5.97	0.07	I
6.17	0.08	I
6.38	0.37	I
6.58	0.64	I
6.79	0.91	I
--->	0.18	I

CHARACTERISTICS
TOTAL FIBERS 6479

CHAR	WEIGHTED		ARITHMETIC
D1	0.66		0.00
Q1	1.25		0.14
Q2	2.35		0.62
Q3	3.85		1.55
D9	6.31		2.93
AV	2.79	4.06	1.33

ANALYZED BY KAJAANI FS-100

1D

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 1DL
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	0.20
0.20	1.14
0.41	3.76
0.61	5.77
0.82	6.72
1.02	7.02
1.23	6.93
1.44	6.17
1.64	5.62
1.85	5.49
2.05	5.74
2.26	5.33
2.47	4.63
2.67	3.98
2.88	4.06
3.08	3.73
3.29	3.59
3.50	3.07
3.70	2.91
3.91	2.56
4.11	2.54
4.32	2.08
4.52	1.73
4.73	1.18
4.94	1.07
5.14	0.79
5.35	0.66
5.55	0.48
5.76	0.44
5.97	0.27
6.17	0.14
6.38	0.03
6.58	0.06
6.79	0.09
--->	0.10

CHARACTERISTICS
TOTAL FIBERS 6926

CHAR	WEIGHTED		ARITHMETIC
D1	0.59		0.00
Q1	1.04		0.26
Q2	1.90		0.70
Q3	3.02		1.46
D9	4.04		2.56
AV	2.12	2.94	1.15

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 1DL
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	10.23
0.20	11.48
0.41	12.64
0.61	11.64
0.82	9.68
1.02	7.86
1.23	6.35
1.44	4.78
1.64	3.77
1.85	3.25
2.05	3.04
2.26	2.56
2.47	2.03
2.67	1.60
2.88	1.51
3.08	1.30
3.29	1.17
3.50	0.94
3.70	0.84
3.91	0.70
4.11	0.66
4.32	0.51
4.52	0.41
4.73	0.27
4.94	0.23
5.14	0.16
5.35	0.13
5.55	0.09
5.76	0.08
5.97	0.05
6.17	0.02
6.38	0.00
6.58	0.01
6.79	0.01
--->	0.01

CHARACTERISTICS
TOTAL FIBERS 6926

CHAR	WEIGHTED		ARITHMETIC
D1	0.59		0.00
Q1	1.04		0.26
Q2	1.90		0.70
Q3	3.02		1.46
D9	4.04		2.56
AV	2.12	2.94	1.15

ANALYZED BY KAJAANI FS-100

3DL

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 3DL
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	0.29
0.20	1.59
0.41	4.64
0.61	6.58
0.82	7.58
1.02	7.72
1.23	8.07
1.44	7.03
1.64	6.39
1.85	5.57
2.05	5.32
2.26	4.87
2.47	4.14
2.67	3.71
2.88	3.89
3.08	3.59
3.29	3.34
3.50	2.65
3.70	2.39
3.91	1.81
4.11	1.61
4.32	1.27
4.52	1.21
4.73	1.00
4.94	0.89
5.14	0.58
5.35	0.42
5.55	0.26
5.76	0.28
5.97	0.29
6.17	0.29
6.38	0.26
6.58	0.25
6.79	0.24
--->	0.24

CHARACTERISTICS
TOTAL FIBERS 6253

CHAR	WEIGHTED		ARITHMETIC
D1	0.52		0.00
Q1	0.94		0.18
Q2	1.65		0.59
Q3	2.76		1.24
D9	3.78		2.21
AV	1.96	2.83	1.02

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 3DL
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	12.82
0.20	13.86
0.41	13.43
0.61	11.44
0.82	9.41
1.02	7.46
1.23	6.37
1.44	4.70
1.64	3.70
1.85	2.85
2.05	2.43
2.26	2.02
2.47	1.56
2.67	1.29
2.88	1.25
3.08	1.07
3.29	0.94
3.50	0.70
3.70	0.59
3.91	0.43
4.11	0.36
4.32	0.27
4.52	0.25
4.73	0.19
4.94	0.16
5.14	0.10
5.35	0.07
5.55	0.04
5.76	0.04
5.97	0.04
6.17	0.04
6.38	0.04
6.58	0.03
6.79	0.03
--->	0.03

CHARACTERISTICS
TOTAL FIBERS 6253

CHAR	WEIGHTED		ARITHMETIC
D1	0.52		0.00
Q1	0.94		0.18
Q2	1.65		0.59
Q3	2.76		1.24
D9	3.78		2.21
AV	1.96	2.83	1.02

ANALYZED BY KAJAANI FS-100

NDM

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE NDMIX
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	0.49
0.20	1.96
0.41	3.62
0.61	4.77
0.82	5.35
1.02	5.37
1.23	5.39
1.44	5.10
1.64	4.99
1.85	5.32
2.05	5.03
2.26	4.94
2.47	4.53
2.67	4.36
2.88	4.44
3.08	4.12
3.29	4.02
3.50	3.69
3.70	3.72
3.91	3.13
4.11	2.66
4.32	1.95
4.52	1.88
4.73	1.55
4.94	1.38
5.14	1.19
5.35	1.24
5.55	1.10
5.76	0.95
5.97	0.60
6.17	0.43
6.38	0.25
6.58	0.25
6.79	0.26
--->	0.32

CHARACTERISTICS
TOTAL FIBERS 7000

CHAR	WEIGHTED		ARITHMETIC
D1	0.58		0.00
Q1	1.16		0.04
Q2	2.17		0.43
Q3	3.36		1.31
D9	4.44		2.60
AV	2.37	3.28	1.14

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE NDMIX
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	21.41
0.20	17.18
0.41	10.59
0.61	8.36
0.82	6.70
1.02	5.24
1.23	4.30
1.44	3.45
1.64	2.92
1.85	2.75
2.05	2.32
2.26	2.07
2.47	1.73
2.67	1.53
2.88	1.44
3.08	1.25
3.29	1.14
3.50	0.98
3.70	0.93
3.91	0.74
4.11	0.60
4.32	0.42
4.52	0.38
4.73	0.30
4.94	0.25
5.14	0.21
5.35	0.21
5.55	0.16
5.76	0.13
5.97	0.09
6.17	0.06
6.38	0.04
6.58	0.04
6.79	0.04
--->	0.04

CHARACTERISTICS
TOTAL FIBERS 7000

CHAR	WEIGHTED		ARITHMETIC
D1	0.58		0.00
Q1	1.16		0.04
Q2	2.17		0.43
Q3	3.36		1.31
D9	4.44		2.60
AV	2.37	3.28	1.14

ANALYZED BY KAJAANI FS-100

1DM

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 1DMIX
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	0.62
0.20	2.84
0.41	5.91
0.61	8.70
0.82	8.88
1.02	8.13
1.23	7.79
1.44	6.92
1.64	6.09
1.85	5.89
2.05	5.00
2.26	4.60
2.47	3.59
2.67	3.18
2.88	3.23
3.08	2.98
3.29	2.89
3.50	2.38
3.70	2.11
3.91	1.44
4.11	1.13
4.32	0.93
4.52	1.12
4.73	0.98
4.94	0.67
5.14	0.31
5.35	0.31
5.55	0.28
5.76	0.27
5.97	0.19
6.17	0.13
6.38	0.12
6.58	0.17
6.79	0.22
--->	0.15

CHARACTERISTICS
TOTAL FIBERS 6625

CHAR	WEIGHTED		ARITHMETIC
D1	0.43		0.00
Q1	0.78		0.05
Q2	1.45		0.38
Q3	2.47		0.94
D9	3.54		1.78
AV	1.77	2.66	0.84

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 1DMIX
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	20.36
0.20	18.66
0.41	12.95
0.61	11.44
0.82	8.34
1.02	5.94
1.23	4.66
1.44	3.50
1.64	2.67
1.85	2.28
2.05	1.73
2.26	1.44
2.47	1.03
2.67	0.94
2.88	0.79
3.08	0.67
3.29	0.61
3.50	0.47
3.70	0.40
3.91	0.26
4.11	0.19
4.32	0.15
4.52	0.17
4.73	0.14
4.94	0.09
5.14	0.04
5.35	0.04
5.55	0.03
5.76	0.03
5.97	0.02
6.17	0.01
6.38	0.01
6.58	0.02
6.79	0.02
--->	0.01

CHARACTERISTICS
TOTAL FIBERS 6625

CHAR	WEIGHTED		ARITHMETIC
D1	0.43		0.00
Q1	0.78		0.05
Q2	1.45		0.38
Q3	2.47		0.94
D9	3.54		1.78
AV	1.77	2.66	0.84

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 3DMIX
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	0.60		I
0.20	2.83	+-	
0.41	6.71	--+---	
0.61	8.23	------+---	
0.82	8.67	-------+-	
1.02	9.24	----------	I
1.23	7.80	--------	I
1.44	6.52	-------	I
1.64	5.44	-----	I
1.85	5.26	-----	I
2.05	5.09	-----	I
2.26	5.02	-----	I
2.47	4.54	----	I
2.67	3.83	---	I
2.88	3.55	---	I
3.08	2.77	--	I
3.29	2.52	--	I
3.50	1.96	-	I
3.70	1.82	-	I
3.91	1.43	-	I
4.11	1.27	-	I
4.32	1.08	-	I
4.52	1.12	-	I
4.73	0.97		I
4.94	0.82		I
5.14	0.51		I
5.35	0.38		I
5.55	0.20		I
5.76	0.16		I
5.97	0.13		I
6.17	0.13		I
6.38	0.14		I
6.58	0.14		I
6.79	0.14		I
--->	0.00		I

CHARACTERISTICS
TOTAL FIBERS 6765

CHAR	WEIGHTED		ARITHMETIC
D1	0.41		0.00
Q1	0.79		0.06
Q2	1.46		0.37
Q3	2.47		0.93
D9	3.55		1.82
AV	1.77	2.65	0.84

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 3DMIX
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	19.77	----+---------------	
0.20	18.60	----------+--------	
0.41	14.67	--------------+	
0.61	10.80	-----------	I
0.82	8.13	--------	I
1.02	6.00	------	I
1.23	4.65	----	I
1.44	3.29	---	I
1.64	2.38	--	I
1.85	2.02	--	I
2.05	1.76	-	I
2.26	1.57	-	I
2.47	1.29	-	I
2.67	1.00		I
2.88	0.86		I
3.08	0.63		I
3.29	0.53		I
3.50	0.39		I
3.70	0.34		I
3.91	0.25		I
4.11	0.21		I
4.32	0.17		I
4.52	0.17		I
4.73	0.14		I
4.94	0.11		I
5.14	0.07		I
5.35	0.05		I
5.55	0.02		I
5.76	0.02		I
5.97	0.01		I
6.17	0.01		I
6.38	0.01		I
6.58	0.01		I
6.79	0.01		I
--->	0.00		I

CHARACTERISTICS
TOTAL FIBERS 6765

CHAR	WEIGHTED		ARITHMETIC
D1	0.41		0.00
Q1	0.78		0.06
Q2	1.46		0.37
Q3	2.47		0.93
D9	3.55		1.82
AV	1.77	2.65	0.84

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE NDFINE
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	12.79	---+--------
0.07	30.42	----------+-------------
0.14	11.44	-----------
0.21	4.75	----
0.28	3.71	---
0.35	3.19	---
0.42	3.38	---
0.49	3.01	---
0.56	1.63	-
0.63	1.29	-
0.70	1.53	-
0.77	2.28	--
0.84	2.94	--
0.91	2.78	--
0.98	2.17	--
1.05	1.44	-
1.12	1.54	-
1.20	1.33	-
1.27	1.08	-
1.34	0.79	
1.41	0.83	
1.48	0.78	
1.55	0.71	
1.62	0.74	
1.69	0.89	
1.76	0.81	
1.83	0.60	
1.90	0.38	
1.97	0.39	
2.04	0.27	
2.11	0.14	
2.18	0.00	
2.25	0.00	
2.32	0.00	
--->	0.00	

CHARACTERISTICS
TOTAL FIBERS 7149

CHAR	WEIGHTED		ARITHMETIC
D1	0.00		0.00
Q1	0.03		0.00
Q2	0.11		0.00
Q3	0.60		0.03
D9	1.12		0.06
AV	0.42	1.01	0.08

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE NDFINE
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	62.96	---------------+--------
0.07	29.94	-----------------------+-
0.14	3.76	---
0.21	0.94	
0.28	0.52	
0.35	0.35	
0.42	0.30	
0.49	0.23	
0.56	0.11	
0.63	0.07	
0.70	0.08	
0.77	0.11	
0.84	0.13	
0.91	0.11	
0.98	0.08	
1.05	0.05	
1.12	0.05	
1.20	0.04	
1.27	0.03	
1.34	0.02	
1.41	0.02	
1.48	0.02	
1.55	0.02	
1.62	0.02	
1.69	0.02	
1.76	0.02	
1.83	0.01	
1.90	0.01	
1.97	0.01	
2.04	0.00	
2.11	0.00	
2.18	0.00	
2.25	0.00	
2.32	0.00	
--->	0.00	

CHARACTERISTICS
TOTAL FIBERS 7149

CHAR	WEIGHTED		ARITHMETIC
D1	0.00		0.00
Q1	0.03		0.00
Q2	0.11		0.00
Q3	0.60		0.03
D9	1.12		0.06
AV	0.42	1.01	0.08

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 1DFINE
SAMPLED TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	15.22
0.07	40.90
0.14	13.34
0.21	3.49
0.28	3.26
0.35	2.54
0.42	1.95
0.49	1.11
0.56	0.83
0.63	0.73
0.70	1.40
0.77	1.29
0.84	1.13
0.91	0.54
0.98	0.66
1.05	1.07
1.12	1.42
1.20	1.62
1.27	1.50
1.34	1.02
1.41	0.72
1.48	0.25
1.55	0.13
1.62	0.14
1.69	0.29
1.76	0.60
1.83	0.78
1.90	0.65
1.97	0.34
2.04	0.17
2.11	0.36
2.18	0.37
2.25	0.19
2.32	0.00
--->	0.00

CHARACTERISTICS
TOTAL FIBERS 6733

CHAR	WEIGHTED		ARITHMETIC
D1	0.00		0.00
Q1	0.02		0.00
Q2	0.06		0.00
Q3	0.26		0.03
D9	1.09		0.06
AV	0.33	1.08	0.06

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE 1DFINE
SAMPLED TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	61.48
0.07	33.03
0.14	3.59
0.21	0.56
0.28	0.38
0.35	0.23
0.42	0.14
0.49	0.07
0.56	0.04
0.63	0.03
0.70	0.06
0.77	0.05
0.84	0.04
0.91	0.02
0.98	0.02
1.05	0.03
1.12	0.04
1.20	0.04
1.27	0.03
1.34	0.02
1.41	0.01
1.48	0.00
1.55	0.00
1.62	0.00
1.69	0.00
1.76	0.01
1.83	0.01
1.90	0.01
1.97	0.00
2.04	0.00
2.11	0.00
2.18	0.00
2.25	0.00
2.32	0.00
--->	0.00

CHARACTERISTICS
TOTAL FIBERS 6733

CHAR	WEIGHTED		ARITHMETIC
D1	0.00		0.00
Q1	0.02		0.00
Q2	0.06		0.00
Q3	0.26		0.03
D9	1.09		0.06
AV	0.33	1.08	0.06

ANALYZED BY KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE   3DFINE
SAMPLED   TESTED ON NOV 15-96

WEIGHTED DISTRIBUTION

0.00	21.08
0.07	56.60
0.14	10.53
0.21	1.99
0.28	1.99
0.35	1.84
0.42	1.27
0.49	1.38
0.56	0.80
0.63	0.75
0.70	0.34
0.77	0.37
0.84	0.20
0.91	0.00
0.98	0.00
1.05	0.13
1.12	0.27
1.20	0.29
1.27	0.16
1.34	0.00
1.41	0.00
1.48	0.00
1.55	0.00
1.62	0.00
1.69	0.00
1.76	0.00
1.83	0.00
1.90	0.00
1.97	0.00
2.04	0.00
2.11	0.00
2.18	0.00
2.25	0.00
2.32	0.00
--->	0.00

CHARACTERISTICS
TOTAL FIBERS   6270

CHAR	WEIGHTED		ARITHMETIC
D1	0.00		0.00
Q1	0.00		0.00
Q2	0.04		0.00
Q3	0.07		0.02
D9	0.20		0.06
AV	0.10	0.38	0.05

ANALYZED BY   KAJAANI FS-100

FS-100 FROM KAJAANI ELECTRONICS
ADDRESS PL177 87100 KAJAANI 10
TEL. 986-3121 / INDUSTRIAL AUTOMATION

SAMPLE   3DFINE
SAMPLED   TESTED ON NOV 15-96

POPULATION DISTRIBUTION

0.00	63.20
0.07	33.93
0.14	2.10
0.21	0.24
0.28	0.17
0.35	0.12
0.42	0.07
0.49	0.06
0.56	0.03
0.63	0.03
0.70	0.01
0.77	0.01
0.84	0.01
0.91	0.00
0.98	0.00
1.05	0.00
1.12	0.01
1.20	0.01
1.27	0.00
1.34	0.00
1.41	0.00
1.48	0.00
1.55	0.00
1.62	0.00
1.69	0.00
1.76	0.00
1.83	0.00
1.90	0.00
1.97	0.00
2.04	0.00
2.11	0.00
2.18	0.00
2.25	0.00
2.32	0.00
--->	0.00

CHARACTERISTICS
TOTAL FIBERS   6270

CHAR	WEIGHTED		ARITHMETIC
D1	0.00		0.00
Q1	0.00		0.00
Q2	0.04		0.00
Q3	0.07		0.02
D9	0.20		0.06
AV	0.10	0.38	0.05

ANALYZED BY   KAJAANI FS-100

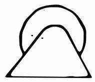
Appendix II

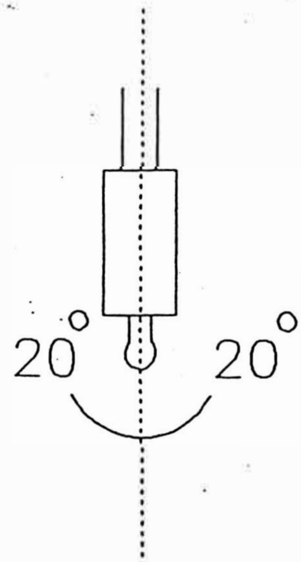
Scott Bond Specs

SCOTT BOND
MANUAL

OPERATOR PROCEDURE

1. Calibration 100+

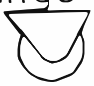
A. Swing the pendulum about 20° and let it come to rest this is the plumb position.(fig 1.)
Put the calibrate ( CAL.) switch in the down position and press and hold the pendulum drop button. The display should read +100. If it does not, turn the knob lock on the 100.0 knob counterclockwise, adjust the knob to obtain +100 reading, and retighten the knob lock. The penduulum drop button must be held in during the entire procedure.



plumb
FIG. 1

OPERATOR PROCEDURE

2. Calibration ZERO

B. Latch and manually drop the pendulum several times to insure the bearings are lubricated and free. (Fig 2.)
Put the calibrate () switch in the up position
CAL.
and latch the pedulum for a drop.

B1. Press the pendulum drop buttom*, then on the return swing catch and relatch the pendulum. Observe the display, the reading should be −19.

B2. If the display isn't −19 turn the knob lock on ZERO knob counterclockwise and adjust the zero knob. Then press the pendulum drop buttom. If the display reads −19 retighten the lock knob. If the display dosn't read −19 repeat steps B1 & B2 until the display does read −19.

* A quick push should be used on the drop buttom.
Your finger MUST be off the buttom before the pendulum reaches its maxium swing.

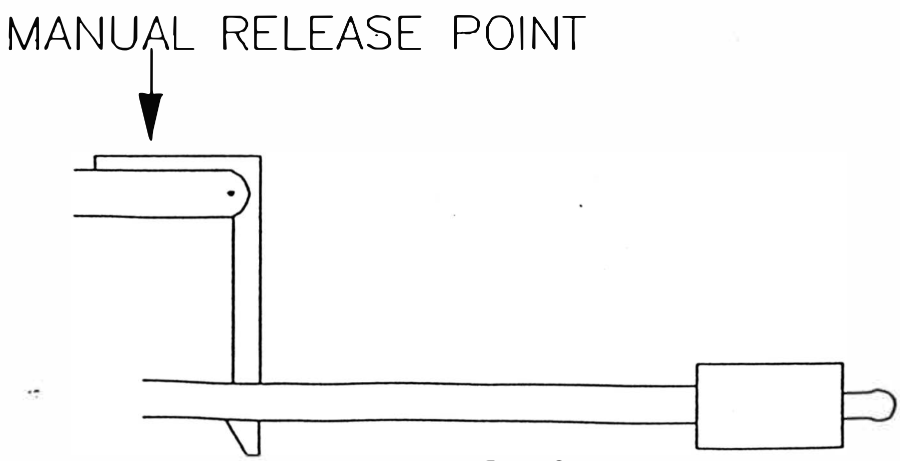


FIG. 2

OPERATOR PROCEDURE

1. Sample testing

A. Prepare samples per Scott instruction (see page 4)

B1. The following procedure must be performed with every set of samples.

Depress average switch ( ) and return to
AVG.

the up position ( ) to clear the unit.
AVG.

B2. Insert the sample anvil and tighten the locking screw.(FIG. 3)

B3. Latch pendulum.

B4. Press the pendulum drop button and release quickly. Catch the pendulum on return swing and relatch.

B5. The display will blank for two seconds and then read the bond strength.

B6. If the paper did not separate, you may elect to to delete the entry by pressing the DEL switch.

B7. Repeat steps B2-B6 for all five samples.

B8. Depress the AVG switch to read the average of the samples. After recording the results return the switch to the up position.

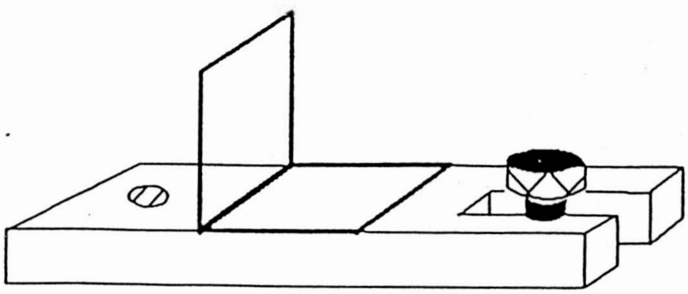


FIG. 3

NOTE : MAX. READING IS 347.

To Assemble Samples

1. Cut paper samples exactly 1 inch wide and 7 inches long. Handels these strips by the ends only.
2. Pull out a strip of tape 22" long.(If any wrinkels appear in the tape discard that section)

   Carefully bring this tape down exactly between the guide pins so that the tapes covers, but does not overlap the the sides of the anvils.
4. Place the paper samples strips in the exact same position on the tape covered anvils so that it is between the four pins and the left ends is at point (B) (see fig. 4 page 5) Do not press it down.
5. Swing the tape hook (31) (see fig 4. page 5) up and over the tape end of sample. With the tape held with slight tension,bring it back across the top of the sample. Cut the doubled tape and sample at point (B) (see fig 4. page 5)
6. With the sample angels in position reassemble the strongback (34) (see fig 4. page 6) on its locating pins.
7. Pull the clamp handel (16) (see fig 4. page 5) as far as it will go for 5 second.
8. Remove the sample avnvils from the strongback assembly (34) (see fig 4. page 6)
9. Separate the samples by inserting the blade of the knife in the spaces between the angles.

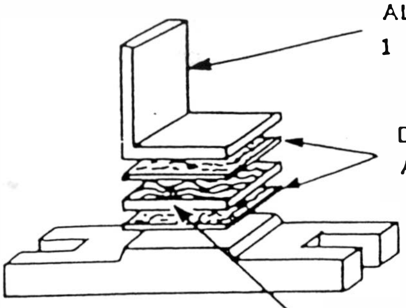
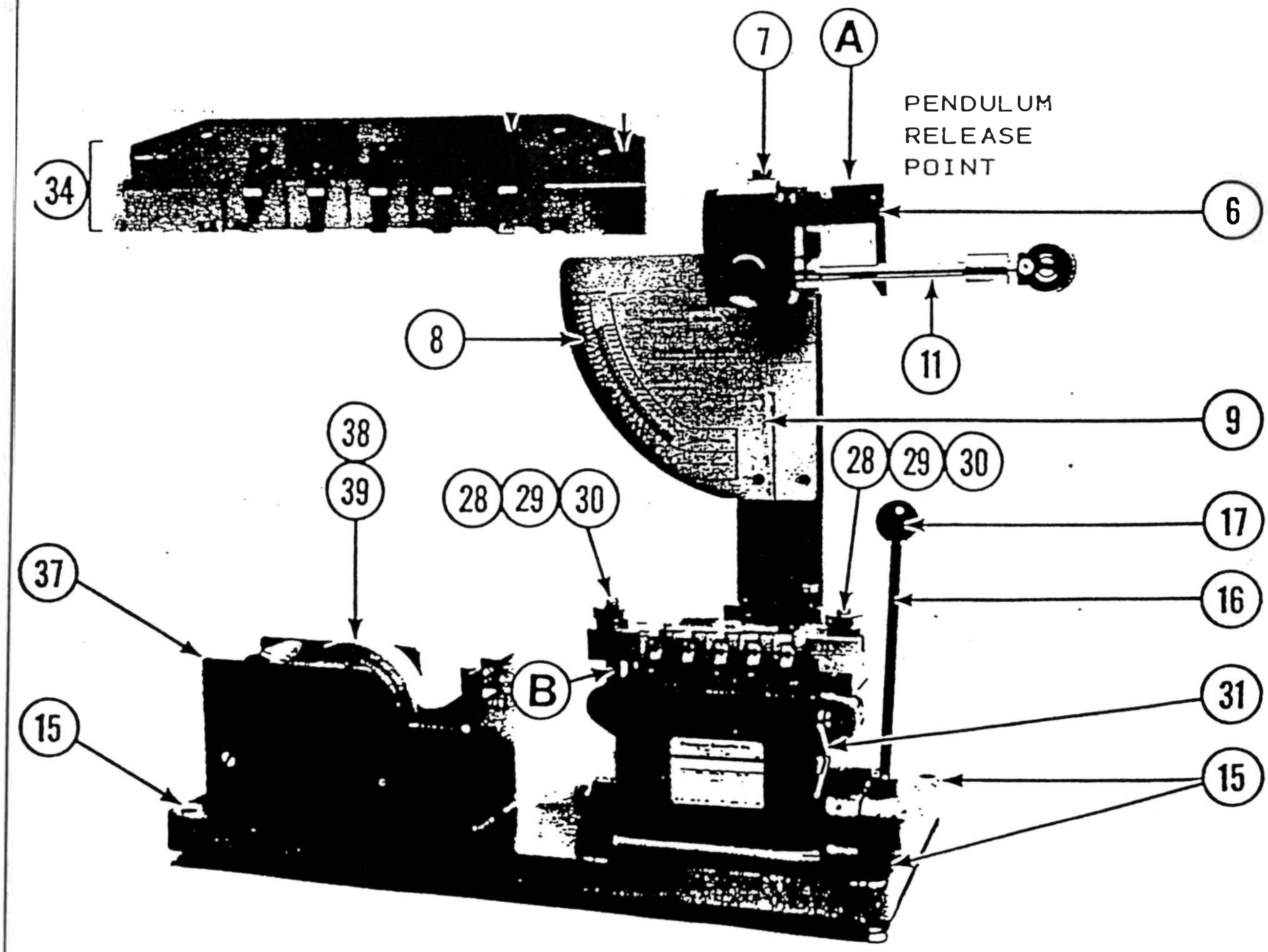

SPECIMEN ASSEMBLY
ALUMINUM ANGLE
1 X 1 X 1 INCH
DOUBLE-SIDED
ADHESIVE TAPE
TEST SAMPLE

FIG. 4


7
A
PENDULUM
RELEASE
POINT
6
34
8
11
9
38
39
28 29 30
28 29 30
17
37
16
B
31
15
15

Parts List

ITEM NO.	DESCRIPTION	QTY.	PART NO.
	Pedestal Assembly		
1.	Nut, Knurled, Tension Adjust	1	B-29
2.	Shoe, Nut	1	B-30
3.	Thumbscrew, Adjust Nut	1	B-38
4.	Spring, Friction	1	B-36
5.	Washer, Friction Bearings	2	B-40
6.	Latch, Pendulum Release	1	B-35
7.	Level, Bubble	1	20601000
8.	Dial, Dual Range, Ft./Lbs. in Thousandths	1	315996
9.	Pointer	1	B-7
10.	Screw, Sample Base, Knurled	1	B-39
11.	Pendulum Assembly	1	B-8
12.	Counter Weight, Low Range	1	B-18
13.	Counter Weight, High Range, Upper	1	B-19
14.	Weight Assy., High Range, Lower	1	701033
	Base Assembly		
15.	Leveling Screws, Base	4	B-114
16.	Handle Assembly, Clamp	1	B-103
17.	Knob, Handle	1	2080301P
18.	Cam	1	B-88
19.	Shaft, Cam	1	B-87
20.	Collar (with Set Screw)	1	B-89
21.	Set Screw	1	268004
22.	Lifter Assy.	5	B-91
23.	Spring, Lifter	5	B-92
24.	Button, 50 lb., Pressure	5	B-93
25.	Washer, 100 lb., Capacity	5	B-94
26.	Washer, 150 lb., Capacity	5	B-95
27.	Washer, 200 lb., Capacity	5	B-96
28.	Locking Bolt	2	B-83
29.	Pin, Locking Bolt	2	B-85
30.	Thumbnut, Locking Bolt	2	B-84
31.	Hook, Tape	1	B-86
32.	Anvil, Sample	5	B-78
33.	Angle, Sample	5	B-82
34.	Strongback	1	B-75
35.	Separator, Strongback	4	B-76
36.	Spring, Strongback Retainer	1	B-77
37.	**Tape Dispenser Assembly**	1	B-109
38.	Spool, Tape Holder	1	B-111
39.	Tape Sensitive	1	20901010
40.	**Sample Knife Assembly**	1	B-115
41.	Handle, Threaded, 6-32	1	B-116
42.	Handle, Countersunk	1	B-117
43.	Blade, Sample Knife	1	B-118
44.	Allen Wrench, 5/32	1	303016
45.	Allen Wrench, 7/64	1	303033